

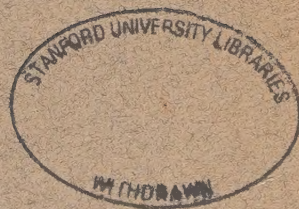
Geology of Bridgewater and Plymouth, Vermont

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Geology of Bridgewater and Plymouth, Vermont

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THE GEOLOGY OF BRIDGEWATER AND PLYMOUTH TOWNSHIPS, VERMONT

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INTRODUCTION

This paper describes the lithology, areal distribution, structure and probable origin and history of the geological formations found in the townships of Plymouth and Bridgewater, Vermont. Particular interest is attached to the rocks of this area since they comprise the lower or older part of an important series of metamorphosed sediments of Central Vermont, the younger members of which have been the subject of long continued study by Dr. C. H. Richardson of the Vermont State Geological Survey. The older members have heretofore never received adequate study and description.

The principal field work upon which this study is based, was carried out during the summer of 1925 under the auspices of the Vermont State Geological Survey. The writer is particularly indebted to Dr. Richardson for his assistance in the field in the month of June, 1925, and for his criticisms and suggestions dur-

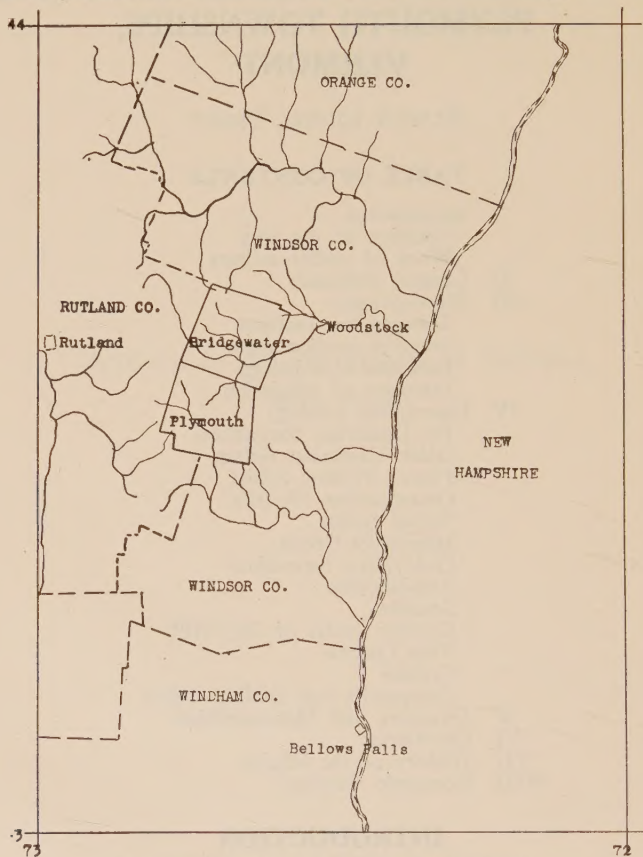


FIGURE 1.—Map of the Area Discussed.

ing the preparation of this report. Thanks are extended to the members of the Department of Geology of Princeton University for their advice and assistance in the study and interpretation of the results of the field work.

LOCATION OF THE AREA

The townships of Plymouth and Bridgewater are located in central Vermont, midway between White River Junction and

Rutland about fifteen miles east of the latter city and fifty miles north of the Massachusetts border. The main range of the Green Mountains extends, with a north-south trend along the western edge of the towns. The area is largely included in the Woodstock quadrangle of the U. S. Topographic Atlas, but portions of western and southwestern Plymouth are included in the Rutland and Wallingford quadrangles respectively and most of the southern part of Plymouth is unmapped. The total area included in the two towns is about one hundred square miles.

PREVIOUS WORK IN THE AREA

Several geologists, especially during the latter part of the last century, have found the geology of Plymouth to be worthy of interest, but in all except one case, observations were confined to special phenomena rather than to a systematic study of the entire area. The mineral deposits of economic value have received the most attention, but the metamorphosed conglomerate of Plymouth also received considerable comment, particularly by Edward and Charles Hitchcock.

In 1861, A. D. Hager in collaboration with Edward Hitchcock and his sons, published a geological map of Plymouth and a very brief description of the geology. This map represents the only systematic work done on the geology of the region up to the present time. Very little differentiation of the formations was attempted by Hager, and although his map is correct in its broadest aspects, the detail is unreliable. The principal authors who have described some special phase of the geology of the region are: the Hitchcocks, Edward, Charles and Edward, Jr., who in several papers have discussed the glacial phenomena, the significance of the metamorphosed conglomerate, the gold deposits and other less important features; Dr. T. N. Dale, who has described the granite and dolomite of Plymouth; Dr. C. L. Whittle, who has studied the Pre-Cambrian rocks of western Plymouth; Dr. Goldthwaite, whose contribution to the interpretation of the glacial phenomena is important; and Dr. G. O. Smith, who has described the economic aspects of the gold deposits.

It is hoped that this paper will contribute to the further understanding of the geology of the eastern Green Mountain belt and form a suggestion for future work in determining the stratigraphy and structure of the early Paleozoic rocks of that region.

GENERAL SUMMARY OF GEOLOGY

The Plymouth-Bridgewater area is a maturely dissected upland with a relief of about one thousand feet. Features indicating two cycles of erosion are present; mature pre-glacial upland and open valleys, and youthful post-glacial tributary valleys.

The principal rocks are the members of a series of metamorphosed sediments ranging in age from Ordovician through probable Cambrian to Pre-Cambrian. Lithologically, the formations are at present: quartzites with various impurities, phyllite, dolomite, quartz-mica-chlorite schist, and many other varieties of schist present in minor quantities. The various rock types outcrop in parallel bands oriented approximately north and south the youngest on the east and successively older bands in order westward.

The metamorphosed sediments are intruded by igneous rocks of at least four different ages and types. In the Pre-Cambrian sediments a granite gneiss is the most common intrusive, although mafic rocks are also present. Intruding the younger sediments, metamorphosed mafic dikes and diorite are the most common. Two types of unmetamorphosed igneous rock are found in the area, a granite of very limited distribution, and many small dikes of diabase and camptonite in widely scattered outcrops. Vein quartz and, more rarely, associated pegmatite is very common throughout the Paleozoic section in the form of small veins and irregular lenses.

Glacial till and glaciofluvial deposits cover much of the country and are of particular hindrance to geological field work in the southwestern part of Plymouth.

The major structure is a homocline, in which the strata strike within a few degrees of north and dip east at angles usually greater than forty degrees. The major structure is complicated, however, by considerable, superimposed, small scale isoclinal folding.

In most of the Cambrian series the bedding and schistosity are parallel, as determined at the contact of beds of unlike lithology. In the Ordovician and uppermost Cambrian a second, partially developed, schistosity which dips north at a low angle, is developed in addition to the schistosity parallel to the bedding, which here dips at very high angles east or west.

PHYSIOGRAPHY

The towns of Bridgewater and Plymouth are situated within the Green Mountain division of the New England Highlands and are characterized by considerable irregularity of surface. The entire region has been reduced to slope, and flat areas are found only on terraces in a few of the larger valleys. On the other hand, the relief is not great, but is about one thousand feet as an average. The elevations above sea level range from 820 feet at Bridgewater on the Ottauquechee River, to 3,278 feet at the crest of Salt Ash Mountain in southwestern Plymouth. Many of the

hills are 2,000 feet above sea level and a few exceed 2,500, but there is no marked accordance of summit levels.

The stage of erosion of the stream valleys ranges from extreme youth to adolescence. Most of the streams are turbulent mountain brooks, occasionally showing in their valley profile the

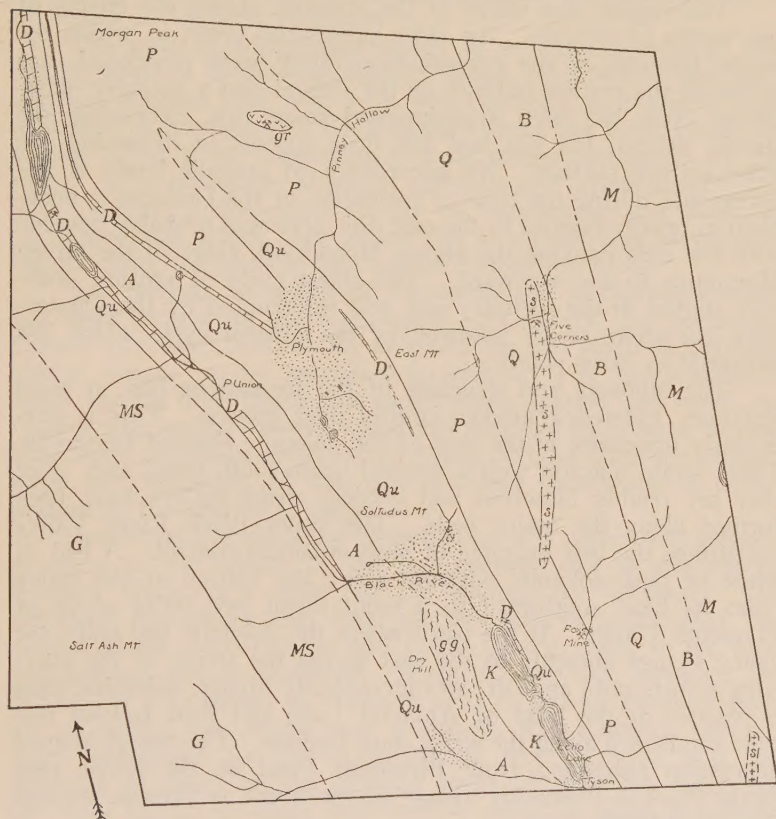


FIGURE 2.—Geological Map of Plymouth, Vt.—1 inch = 1.75 miles.

M—Missisquoi Group, B—Bethel Schist, Q—Ottawaquechee Group, P—Pinney Hollow Schist, Qu—Quartzites, K—Conglomerate, D—Dolomite, A—Albitic Schist, MS—Mendon Series, G—Mt. Holly Series and Gneiss, s—Steatite, gr—Granite, gg—Granite Gneiss of Dry Hill, Stippling—Glaciofluvial Deposits.

effects of two cycles of erosion; an older cycle which had reached a submature stage before the start of the present one, which has resulted in the incision of sharp gorges in the older valleys. The larger streams such as the Ottawaquechee and lower Black Rivers, have reached a subgraded condition, although the gradients are as yet too high for mature streams, and there is little tendency

indicated toward a widening of the valleys by lateral erosion. Much of the drainage of the large streams is affected by the presence of glacial deposits in the valleys, and lakes are occasionally formed. The influence of glaciation on topography will be considered more at length below.

The region, like many of the streams, shows the effects of two cycles of erosion. An older pre-glacial cycle, in which the major features of the present topography were developed, has produced the mature outlines of the upland and a younger, post-glacial cycle has been superimposed upon this, deepening the stream valleys, but has had but little success in dissecting the older mature surface. No accordance of summit levels is apparent and during the time of formation of the Cretaceous peneplain in nearby regions to the east, this area was probably covered with low hills flanking the higher Monadnock ridge of the Green Mountains to the westward. The oldest cycle of erosion probably started in the Tertiary and was interrupted by the Quaternary glaciation, to be followed by the present cycle which has advanced to early youth.

The lithology and structure of the formations has, in some instances, exerted a marked control over erosion. This is particularly noticeable in the case of the dolomite beds of Plymouth. These strata outcrop with a general north-south trend and, since they are readily dissolved and eroded, strike valleys have been formed along the major beds. The upper Black River Valley constitutes the best example of such erosional control. A bed of white or pink dolomite outcrops along the bottom of the valley from its head southward to a point about two miles south of Plymouth Union. At the place where the dolomite bed ends, the valley swings abruptly to the east across the strike of the overlying schists until another, stratigraphically higher, dolomitic zone is reached at the head of Amherst Lake and then follows this zone southward along the strike, into Ludlow. The trough-shaped depression extending from Plymouth Pond on the north, past Grass Pond to Plymouth Village on the south, is likewise formed along a dolomite zone.

Just as the dolomites tend to cause valleys, some of the more resistant schists and quartzites tend to form ridges or lines of hills. The very pronounced range of hills extending north from Bridgewater Village follows just east of the line of contact of the Ordovician phyllite and the Pre-Ordovician schists (see map) and is undoubtedly influenced by the resistance of the phyllite to erosion. To a lesser extent, the Bethel and Pinney Hollow Schists, very similar in lithology, have favored the formation of hills. Many of these hills have a gentle eastward slope due to the eastward dip of the bedding and an abrupt westward declivity, brought about by the control exercised by a persistent

system of joints parallel with the strike and at right angles to the easterly dip of the schistosity. This same feature of gentle eastward and steep westward slope is illustrated along the east side of the Black River Valley in the older Cambrian rocks. Occasionally well defined dip slopes have been formed, as on the quartzites east of Tyson, or on the quartzite conglomerate north of Tyson in southern Plymouth.

The type of topography which is so characteristic of the nearby town of Woodstock, namely broad, open valleys and rolling, soil-covered hills with very few outcrops, is found in this area only in northeastern Bridgewater, where the belt of outcrop of the Waits River Limestone extends across the corner of the town. This limestone, although siliceous and often interbedded with phyllite, disintegrates readily by weathering and tends to form moderate slopes, thus giving rise to a much less precipitous country than the gneisses and schists to the westward.

The igneous intrusions of Plymouth and Bridgewater exert but little control on the topography. In general the metamorphosed intrusives, such as the amphibolites and steatites, produce effects similar to the surrounding schists. The lamprophyric dikes, on the other hand, are considerably jointed and break up readily into separate blocks which are removed by erosion so that long trench-like depressions often result. These dikes are neither large nor numerous, so that this erosional phenomena is unimportant in the area as a whole.

Interest in the effects of glaciation on this region was evinced as early as the middle of the last century and is stressed in Edward Hitchcock's report on the geology of Vermont.¹ He advanced the theory that *local* glaciers had once occupied the valleys of the Ottauquechee and Black Rivers, rising in the hills and flowing east or southeast. Hitchcock did not, however, attribute the distribution of ordinary drift to strictly glacial action, but advocated the theory then prevalent, that floating icebergs were responsible for the scattering of drift material and the grooving of striae on the exposed rocks of the hills, reserving the term glacial to apply only to the work of local, mountain glaciers. As late as 1908, C. H. Hitchcock² has advocated the former presence of valley glaciers in the Ottauquechee district, but Goldthwaite³ presents a clear case to the contrary and his observations are readily confirmable in the field. No cirques are present to serve as gathering grounds for snow and the phenomena such as heaps of glacial-borne material in the valleys, cited by the Hitchcocks as terminal moraines of valley glaciers, have been

¹ Hitchcock, E., Sr., *Geology of Vermont*, Vol. I, 1861, pp. 85-86.

² Hitchcock, C. H., *Rpt. Vermont State Geologist*, Vol. VI, 1907-08, p. 180.

³ Goldthwaite, J. W., *Rpt. Vermont State Geologist*, Vol. X, 1915-16, pp. 42-73.

found to be kames of glaciofluvial origin and were probably formed by the water from local tongues of ice extending from the margin of the retreating continental ice sheet. It is evident that all the glacial phenomena of the district are to be attributed to continental glaciation; the chief effects of which are the kames and terraces in the valleys and unsorted drift and smoothed, striated rock ledges on the hills.

Kames are particularly common near West Bridgewater, in the vicinity of Plymouth Village, the head of Amherst Lake, and near Tyson in southern Plymouth. A typical isolated kame is that between Amherst and Echo Lakes. This has been cut into for road material and shows distinct stratification and sorting of the constituent sand and gravel. The deposition of kame material has been responsible for the formation of most of the ponds and lakes of the district. The deposits at the head of the "Old Notch" near Plymouth Village have, as Goldthwaite has pointed out, obstructed the course of the glacial (and pre-glacial?) stream which carved this notch and have diverted the drainage from the Black River to the Ottauquechee, after the melting of the ice had freed the outlet through Pinney Hollow to the northeast.

Terraces of glaciofluvial origin are common in the major stream valleys, particularly along the North Branch of the Ottauquechee and in northern Hale Hollow and Pinney Hollow, and lake terraces are evident on the east shore of Echo Lake. The stream valley terraces are found only near the valley bottoms and vary in height from about five to twenty-five feet. As many as six small terraces totaling no more than fifty feet may be present, as at Bridgewater Corners where the North Branch joins the main Ottauquechee. The terraces do not persist at any one level, but vary locally, hence are considered to be the result of deposition by rivers. They are most commonly found where tributary streams enter larger ones and may thus be in part, delta deposits. The terrace at Tyson, where Patch Brook enters the Black River, is an illustration. The well-preserved terrace on Echo Lake near the mouth of Kingdom Brook is very probably a delta deposit formed by the brook entering the lake when the level of the latter was about thirty feet higher than at present. A narrow lake terrace which is persistent at this same level on the eastern side of the lake was probably formed along the shore at that same time.

Glacial till made up of compact clay with imbedded pebbles and boulders is occasionally present on hillsides, particularly on those with northern exposure, and is revealed on the banks of the smallest brooks. The best example of such deposits was noted on the northwest side of Dry Hill in southern Plymouth. The till contributes to the filling in of irregularities in the underlying

rocky floor and hence aids in the smoothing out of the surface contours.

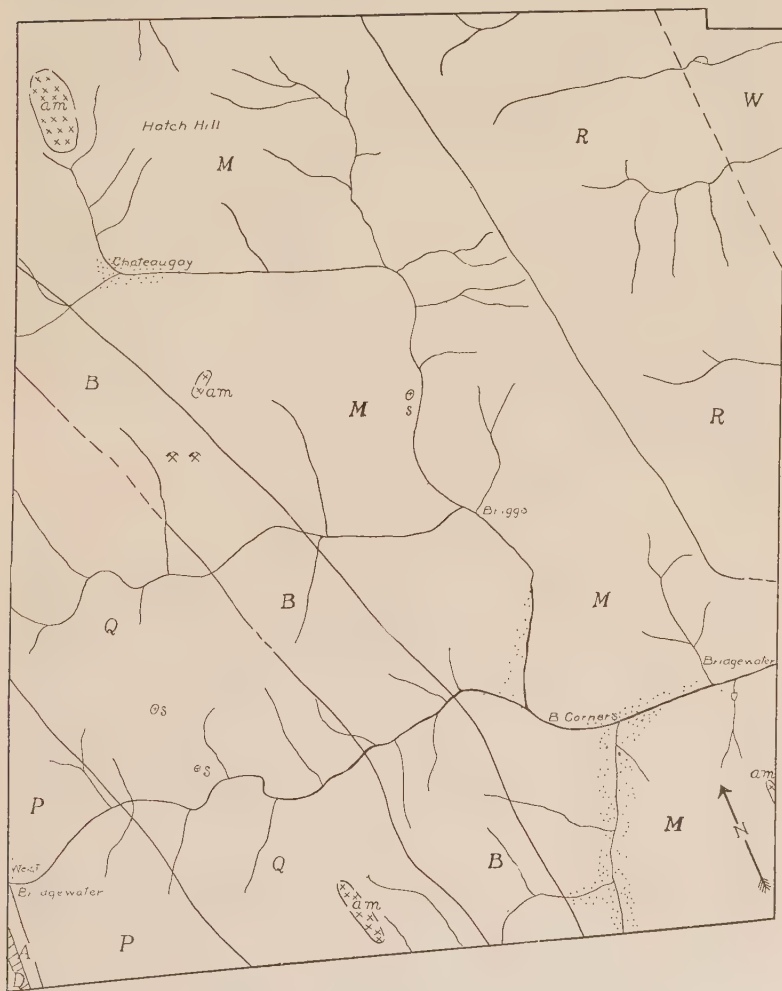


FIGURE 3.—Geological Map of Bridgewater, Vt.—1 inch = 1.6 miles.

W—Waits River Limestone, R—Randolph Phyllite, M—Missisquoi Group, B—Bethel Schist, Q—Ottawaquechee Group, P—Pinney Hollow Schist, A—Albite Schist, D—Dolomite, am—Amphibolite, s—Steatite, Stippling—Glaciofluvial Deposits.

The erosional effects of glaciation are most apparent on the bare ledges, both in the valleys and on the hills. Most of the outcrops are distinctly rounded and bear striæ oriented in a

northerly direction, although they are somewhat variable, particularly at low elevations. A second type of erosional feature, due secondarily to glaciation, is the abandoned stream channel between Plymouth Pond and Black Lake in northwestern Plymouth. This channel has the form of a gorge about twenty feet deep, known locally as "The Narrows," and was formed chiefly in a bed of dolomite, although it is also cut in the quartzites on either side. In the latter, several large pot holes and chutes are well preserved; the best of these a few yards south of the head of Plymouth Pond, are of considerable size, ten or more feet across, and could not have been formed by any stream now present in the vicinity. This channel is clearly a result of glaciofluvial erosion and must have been formed when the valley to the north was blocked, probably by a local ice tongue, and the drainage from that district into the Ottauquechee was diverted southward into the present Black River valley. The erosion channels known locally as the "old" and "new" notches near Plymouth Village, and which have been mentioned above, are similar abandoned stream beds of glaciofluvial origin.

DESCRIPTIVE GEOLOGY

PRE-CAMBRIAN

Very little progress can be made in classifying the Pre-Cambrian rocks of Plymouth because of the pronounced lack of connected outcrops. It is evident, however, that a broad subdivision into two parts is possible; an eastern belt of highly metamorphosed sediments and a western area in which metamorphosed igneous rocks associated with occasional sediments of an older series are predominant. The eastern group is probably the Mendon Series,¹ the younger Pre-Cambrian of the Green Mountain region, while the western group includes the Mount Holly Series, or older group of Pre-Cambrian sediments, intruded by igneous rocks. The type locality of the latter series is in the town of Mount Holly, adjoining Plymouth on the southwest. The Mendon Series takes its name from the town of Mendon where it is best exposed on the western side of the Green Mountains, about ten miles northwest of Plymouth.

Both of these series of rocks were considered by Whittle to be of Algonkian age, but the term Algonkian was not used at that time (1894) in the same sense as it is employed at present. The Algonkian System was originally defined in 1889 as including all Pre-Cambrian *clastic* rocks² and would thus include part of the present Archean as well as portions of the present Algonkian. In view of more recent research and nomenclature it is

¹ Whittle, C. L., Jour. Geol., Vol. II, 1894, pp. 396-429.

² Wilmarth, M. Grace, U. S. G. S. Bull. 769, 1925, p. 103.

more probable that the Mount Holly Series is Archean in age, and possibly Grenville, although no convincing proof can be offered in support of the latter thesis at the present time. The apparent complexity of structure, the degree of metamorphism, and the presence of numerous areas of carbonate rocks are all strongly suggestive of a close relationship between the Mount Holly Series and the Grenville Series of eastern New York State.

The Mendon Series is particularly well exposed in a few tributaries on the west side of Black River but the Mount Holly Series is largely covered by high level swamp and till deposits so that outcrops are small and often widely scattered except on occasional, steeply sloping hillsides. The best exposures of the latter series are on the southeast slopes of Salt Ash Mountain, and Proctor Hill nearby.

THE MOUNT HOLLY SERIES

Three distinct types of metamorphosed sediments were recognized in the Mount Holly Series in Plymouth, but no effort was made to separate the different types in mapping. Dolomite found on the north side of Proctor Hill on the Plymouth-Shrewsbury line, is the most unquestionable sediment. The rock is light grey both on the fresh and weathered surfaces and shows little effect of weathering other than solution of the carbonate minerals. The dolomite is fine grained and completely re-crystallized. Small veinlets of clear colorless quartz are occasionally present, and in the vicinity of these the carbonate is as coarse as one millimeter in grain and has been partially changed to calcite. The relation of the dolomite to the other formations is indeterminate at this locality because of surrounding glacial drift. Similarity between this dolomite and those of the Cambrian series to the east is not marked, although in size of grain and color it does resemble the youngest of the Cambrian dolomites, just beneath the Pinney Hollow Schist.

Several localities at which "limestone" occurs, are mentioned by Whittle¹ in his description of the Mount Holly Series of the adjoining type region.

"A section on the southwest slope of Ludlow Mountain, . . . , exhibits at least two beds of coarse limestone grading into tremolite and green hornblende, interstratified with layers of schist. On the southwest slope of Salt Ash Mountain a bed of tremolite limestone interstratified in biotitic gneiss trends northwest. At Northham village, a similar coarse limestone occurs associated with a vitreous quartzite, a laminated eruptive rock and a rusty muscovitic schist. All through the core there are patches of these coarse limestones in a great variety of association, such as with coarse augen-gneisses (a common occurrence), quartzites, schists, and other rocks. Fine-grained blue marbles are present in two or three localities. In all cases the limestones are in irregular lenses, and are extremely local; their occur-

¹ Whittle, C. L., *Jour. Geol.*, Vol. II, 1894, p. 415.

rence with coarse gneiss affords no evidence of structure; these scattered irregular outcroppings and differences of association make them impossible of correlation. There may be two horizons of limestone in the core or there may be a dozen. The same is true of the quartzites and other sedimentary rocks."

Dale,¹ more recently, has described several occurrences of dolomite in the lower Pre-Cambrian rocks of the towns to the south and west of Plymouth. His observations agree in the main with those of Whittle, particularly in regard to the association of schists and gneisses with the dolomites.

White quartzites are often present in the glacial drift of southwestern Plymouth as subangular blocks, and have probably been derived from strata of quartzite in the Mount Holly Series, particularly from the east side of Salt Ash Mountain and possibly from other localities now under cover. These quartzites differ from those of the younger rocks in that they are more vitreous and less granular. Outcrops of the quartzites are rare, in Plymouth, and do not clarify the question of their relationship to the other rocks of the series. Coarsely banded schistose quartzites, containing biotite, are present in the injection gneiss of Salt Ash Mountain on the southeast side, near the crest. These probably represent impure, possibly shaly, sandstones especially since they are associated with considerable thickness of chlorite schist, which were most probably shales before metamorphism.

In addition to the dolomite and quartzite, a third type of rock which may be a metamorphosed sediment is found in the lower Pre-Cambrian of Plymouth. This rock is a chlorite-sericite-quartz schist, predominantly chloritic, injected by layers of younger granitic material *lit par lit*. This type of rock is exposed over a vertical range of more than one thousand feet on the south slope of Salt Ash Mountain and is by far the most common rock type in the older Pre-Cambrian of the district. The layers of altered granite range in thickness from microscopic laminæ up to irregular sheets more than a foot in thickness.

The schist is uniformly dark green and fine textured with well-defined parting produced by the parallel orientation of plates of chlorite. Small flakes of biotite are occasionally present and fine granular quartz is consistently present as scattered grains in the chlorite. The mineral composition and structure of the schist over a considerable area are considered as indicative of a probable sedimentary origin.

The igneous material intrusive into the chlorite schist is clearly granitic in composition. Orthoclase is the most prominent mineral and occurs as distinct crystals, often rounded, and of a size proportional to the thickness of each individual layer of granite. Abundant layers about one-half inch in thickness

¹ Dale, T. N., U. S. G. S. Bull. 589, pp. 20-22.

contain feldspars about one-eighth inch in diameter, and layers six inches or more in thickness contain feldspars three or four inches across. Finely granular quartz encloses the feldspar and the structure of the whole, indicates considerable shearing. Most of the granitic layers alternately swell and pinch along the strike, so as to produce a series of lens-shaped masses. Sericite and chlorite are accessory minerals, but are present only in small quantities. The color of the rock is characteristically a dull white with but few dark minerals.

In addition to the igneous rock of the injection gneiss described above, two other distinct types of metamorphosed intrusives were noted in the district. A massive granite gneiss is well exposed on the north slope of Proctor Hill, in the southwest corner of Plymouth, in large, well-rounded ledges. The rock is predominantly white or light pink with narrow bands of green chlorite. The important minerals are quartz and feldspar, the former slightly in excess of the latter. Both minerals occur as irregular interlocking anhedral grains of even distribution and 0.5 mm. or less in size. The feldspar is mostly orthoclase, but a minor amount of albite showing coarse twinning and a higher index of refraction, is also present. The presence of a few narrow veinlets of clear quartz grains is interpreted as indicating movement, probably shearing, across the planes of schistosity and later healing of the fractures by the crystallization of second generation quartz. Muscovite is common, roughly segregated in bands made up of bundles of coarse laths, often associated with large irregular flakes of chlorite. Epidote is abundant as grains 0.3 mm. or less in cross-section and often columnar, cutting the four minerals mentioned above. Many crystals of feldspar, and the earlier quartz, are clouded with minute epidote grains. Apatite, diotite, chlorite and hematite are accessory minerals, the latter causing the pink color of the rock.

The composition and structure of the gneiss are interpreted as indicating an original biotite-muscovite granite in which recrystallization has occurred, with the formation of epidote and chlorite at the expense of the original feldspar and biotite or other mafic minerals, respectively. Similar gneisses are very common in the glacial drift of the vicinity.

On Great Roaring Brook near the Shrewsbury line, 1.2 miles west of Plymouth Union, a small area of metamorphosed basic igneous rock is exposed, underlying the Mendon Series. The principal rock type is an epidiorite with slightly schistose structure and composed of approximately equal proportions of hornblende, and feldspar and quartz. This gneiss is overlain by, and encloses, irregular areas of a massive moss-green rock apparently an altered phase of the diorite. This rock is composed almost entirely of chlorite enclosing small patches of calcite. The composition and

relation of the chloritic rock to the diorite suggest that the former represents either a metamorphosed contact phase of the latter, or a weathered zone formed prior to the deposition of the overlying Mendon Series and since metamorphosed. The diorite is intruded by veinlets of both granular quartz and pegmatite.

MENDON SERIES

The Mendon Series in Plymouth consists in general of micaceous quartzites, quartz-muscovite chlorite schists and some coarse limestone containing abundant micaceous minerals. The various lithological types each show complete recrystallization of the major constituents and retain but few of the original sedimentary characters. All members of the group which were studied are, however, considered to be former sediments because of their individual mineral compositions and distinctly stratified arrangement. The belt of outcrop of the series is about a mile wide, bordering the Mount Holly Series on the east. Structurally, the Mendon Series is less complex than the older Mount Holly Series, but small close folds, overturned from east to west are common in some of the less massive members. It is probable that larger isoclines are also present in which overturning of the beds has produced the present dip of about twenty-five degrees east, but conclusive evidence of such folds is not present in the Plymouth area.

Three excellent sections are exposed across the strike of the formation along Tinker Brook, Great Roaring Brook and Little Roaring Brook, but the intervening areas exhibit only scattered outcrops of obscure relationships. The three sections, although similar in the general character of the rocks exposed, differ in detailed appearance and order of succession of rock types.

The Roaring Brook section, west of Plymouth Union, is considered to be the best local exposure of the Mendon Series, because the section is nearly complete from a gneiss at the base to the Cambrian dolomite at the top. The rocks outcrop in the bed of the brook and along the valley sides for a distance of slightly less than a mile and the elevation drops from 1,830 at the lower contact to 1,300 at the contact with the Cambrian. The total *apparent* thickness of the section is about 2,200 feet, but this is undoubtedly greater than the actual thickness because of close folding and minor overthrusting of which there is considerable evidence.

All the rocks of the Roaring Brook section are distinctly schistose and are consistently made up of the four minerals, quartz, chlorite, muscovite and magnetite, as essential constituents. These minerals are usually very well crystallized, much more so

than in the case of the minerals in the rocks which overlie the Mendon Series. Accessory minerals which are recognizable in a microscopic examination are calcite, pyrite and feldspar. Quartz is by far the most abundant mineral. The rock types vary between two extremes and are found in all gradations between a chloritic mica schist and a micaceous, chloritic quartzite, although the latter is the most abundant type. The absence of strongly contrasting or unique beds in the section renders impossible the establishing of a datum plane for solving the structures and stratigraphic sequence of the beds. In general, the lower part of the formation is here made up mostly of fine-textured pale green chlorite-mica schists, the middle part of coarser, light colored, highly quartzose schists and the upper part of dark green, somewhat granular quartz-chlorite schist intermediate between the other two in composition.

A microscopic examination of the more quartzose phase of the formation shows the following minerals: *quartz*, abundant as anhedral grains up to 0.5 mm. in diameter evenly distributed through the rock, and with inclusions of chlorite, mica, rutile and zircon; *chlorite*, abundant as irregular patches, usually with parallel elongation, well crystallized, in size up to 1.0 mm. in length; *muscovite*, common as well defined laths surrounded by quartz; *calcite*, common as small irregular interstitial grains; *zircon*, a few oval grains not more than 0.1 mm. in size, probably original clastic grains; *rutile*, common as groups of tiny, dark brown needles in the quartz; *apatite*, occasional subhedral shattered grains; *epidote*, in occasional irregular grains, slightly shattered and altered; and *feldspar* of somewhat doubtful composition, probably albite ($Ab_{90} An_{10}$) as determined from a few, simply twinned, anhedral crystals.

The Tinker Brook section in northern Plymouth, about a mile north of Great Roaring Brook, is essentially the same as the section described above, with but one notable exception. A new group of closely associated rocks, outcrops at an elevation of 1,600 feet beside the brook. They consist of a white, slightly micaceous quartzite overlain by limestone interbedded with chloritic schist. The quartzite shows zones of shearing and the limestone is strongly contorted, often showing flowage, where etched by weathering, and is drawn out into small lens-shaped masses enclosed by schist. The limestone has a rough distribution in layers a few feet thick, striking north and dipping twenty degrees east, and interbedded with quartzites or schist. The other rocks of the section above and below the quartzite-limestone horizon bear a marked resemblance to those of Great Roaring Brook, although there is more feldspar in most of them and the quartz, although

granulated, often preserves outlines suggesting rounded sand grains.

In southern Plymouth the best section through the Mendon Series is exposed on Little Roaring Brook, east of the crest of Salt Ash Mountain. The series of outcrops is, however, not as complete as in the two northern sections. The lowermost formation here exposed is a white, sugary quartzite with grains of bluish quartz about 1.0 mm. in diameter, scattered through it. A small amount of biotite and sericite is developed as small flakes. The formations overlying the quartzite are similar to those of the other sections, dark, highly quartzose, mica-chlorite schists with considerable accessory calcite and some biotite.

Outcrops of the Mendon Series near the southern border of Plymouth are scarce, but the exposures on Patch Brook and the crest of Tinney Hill, west of Tyson, are enough to show the similarity of the rocks there to those farther north.

The Mendon Series is considered by the writer to represent a group of metamorphosed shales, limestones and sandstones, with many intermediate mixed varieties among these three simple types.

AGE OF THE POST-CAMBRIAN FORMATIONS

The rocks which overlie the Pre-Cambrian formations are divisible into two main groups; a series of quartzites, dolomite and various schists, overlain by a second group made up of a limestone and associated phyllite. The latter group is of known Ordovician age, as determined by fossils in areas to the north along the strike, but the former is of indefinite age. It seems advisable to refer this series provisionally to the Cambrian, for three reasons: 1. The approximate extension of this series to the north into Canada is referred to the Cambrian by the Canadian Geological Survey (on meager paleontological evidence); 2. the position of this thick series between Ordovician and probable Pre-Cambrian rocks with unconformities separating it from each, infers a Cambrian age; 3. a considerable thickness of Cambrian sediments of proven age is present on the western side of the Green Mountains only a few miles away and it seems reasonable in view of the fact that the sediments on both sides of the axis were very evidently similar in lithology before metamorphism, that sedimentation went on simultaneously on both sides of the axis during the Cambrian and that the series in the area under discussion is the counterpart of the known Cambrian to the west. Thus although a Cambrian age can not be proved for this group on direct paleontological evidence, it will be described as of that age by the writer.

OLDER CAMBRIAN GROUP

Outcropping in a belt to the east of and overlying the Mendon Series is a group of related formations, several with very distinctive lithology, but of such limited persistence along the strike that it is considered impractical at present to suggest separate formation names for the different lithologic units. The group is overlain and limited on the east by the Pinney Hollow Schist, which has an appearance sharply in contrast with that of the older rocks. The contact between the two is comparatively sharp, *i.e.*, the contact can be located within ten feet at several places.



FIGURE 4.—Basal Quartzite, Cambrian, showing easterly dip, East Bridgewater.

The chief rock types of the older Cambrian group are: quartzite of several varieties, conglomerate, dolomite, and a dark, mica schist containing many small phenocrysts of albite. The group is most conveniently described by tracing the changes in lithology which take place in each unit of the section from north to south along the strike. The best, most continuous outcrops are those at the west base of Morgan Peak in northern Plymouth and in the vicinity of Solitudus Mountain in the center of the town.

LOWER QUARTZITE AND DOLOMITE

The basal beds of the main sequence consist of a variable group of rocks, chiefly dolomite and white quartzite, two hundred feet or less in thickness. This group is best exposed in north-

western Plymouth at the Bridgewater line and at the "Narrows" at the head of Plymouth Pond. Individual layers vary considerably along the strike although the lithology of the group as a whole is constant. The lowest beds are quartzite, either white or light grey, and containing occasional dolomitic and pebbly layers. The major thickness of the quartzite is attained in the northwest corner of Plymouth and decreases from about one hundred feet in that district to one quarter that thickness in southern Plymouth. The rock is distinctly granulated and has cataclastic structure, although pebbles of bluish granulated quartz have undergone very little distortion during the movement producing this structure.

The basal quartzite member grades upward into a persistent horizon of dolomite, which in northern Plymouth is about forty to fifty feet thick. This thickness, like that of the underlying quartzite, decreases to the south and is less than five feet at a point two miles south of Plymouth Union, where it disappears beneath glacial drift. The dolomite is situated in or near the bottom of the Plymouth Valley throughout its length and was probably the controlling factor in the formation of the latter. Although sometimes siliceous and nearly a quartzite in composition, the dolomite is largely pure and is either white or light pink. The rock is completely recrystallized, but is of very fine grain. The pink color is referred by Dale¹ to the presence of manganese and iron in small amount. Most of the lime production of the district was derived from this main bed of dolomite, north of Plymouth Union.

The strata overlying the dolomite are white and sandy, with some patches of dolomite and often with large subhedral orthoclase crystals, up to eight millimeters in cross-section. Much of the orthoclase is pink and has tiny inclusions of hematite and chlorite oriented parallel to the principal cleavage direction. Many of the grains are well rounded and appear to be clastic derivatives of the feldspar from a coarse granite. Grains of quartz of a size comparable with the feldspar are occasionally present, but most of the quartz is completely recrystallized to a very fine grain in which the outlines of the larger primary clasts are still visible. Much of the orthoclase is also fractured so that the whole rock has a cataclastic structure in which the quartz is much more granular than the feldspar.

ALBITIC MICA SCHIST

In a persistent bed outcropping above the quartzite-dolomite group, is an unusual variety of black, porphyritic mica schist. This constitutes a distinct, continuous formation about nine hun-

¹ Dale, T. N., U. S. G. S. Bull. 589, 1915, p. 27.

ded feet thick extending along the steep westward-sloping hillside on the east side of the Black River Valley, from northern Plymouth as far south as the curve of the river at Solitudus Mountain. South of there the formation is largely under cover of glacial drift, but seems to thicken considerably in the Patch Brook valley, although this may in part be due to the intrusion of granite (gneiss) on the east crest of Dry Hill within the belt of outcrop of the schist.

The rock is distinctly schistose and is characterized by a porphyritic texture, but with the phenocrysts (metacrysts) not more than 3.0 mm. in cross-section. The formation is quite uniform in lithology along the entire belt of outcrop. The color of the ground mass of the rock is uniformly dark grey or black, in contrast with the small metacrysts of colorless or white albite and quartz. The essential minerals are: Quartz, as small, angular, anhedral grains about 0.2 mm. in size and often segregated in groups; muscovite, common as bundles of fibers with parallel orientation; chlorite, abundant as blades and patches, often with inclusions of accessory minerals; and plagioclase, albite to oligoclase, as simple twinned or untwinned crystals with many inclusions of the other minerals. The accessory minerals are: Tourmaline, as blunt prisms 0.3 mm. or less in length, some of which may be rounded primary clastic grains; zircon, as occasional well-rounded grains, in one instance with a surrounding pleochroic halo in chlorite; magnetite (and ilmenite?) common as small irregular patches and dots scattered rather evenly through the schist; and biotite, as scattered groups of blades, largely altered to chlorite and magnetite and scarcely recognizable.

The rock resembles a mica schist derived from the metamorphism of a shale except in one regard, the presence of the abundant albite representing a proportion of sodium abnormal in an ordinary sediment. As judged from its appearance in thin sections the albite is undoubtedly secondary. It is furthermore not confined to the albitic schist in its distribution, but is also common in the overlying quartzite and conglomerate often as large well-defined euhedral crystals. Upon this fact is based the conclusion that the materials necessary for the formation of the albite were introduced during, or after, the principal metamorphism of the original sediments. The original form of the present albitic schist is considered, by the writer, to be a black shale. Evidence to uphold this view was discovered in the formations overlying the schist. Angular fragments and tiny lenses of shale were found enclosed in the quartzite and dolomite above, in which they had been protected from the considerable stresses to which the less competent underlying shale reacted.

MIDDLE QUARTZITE, CONGLOMERATE AND DOLOMITE

Above the albite schist and extending from Morgan Peak on the north to Solitudus Mountain on the south, is a series of massive quartzites in beds from three to six feet thick and with very uniform dip of about forty-five degrees east. The thickness of this formation is in doubt in the Morgan Peak section but reaches a maximum of slightly over seven hundred feet in the vicinity of Plymouth Notch. The best exposures are on the east slopes of the hills on either side of the "Notch," where the characteristic habit of outcrop of this quartzite is well shown. The rock is very resistant to decomposition, but a persistent system



FIGURE 5.—Metamorphosed Conglomerate, Tyson.

of joints at right angles to the bedding and parallel with the strike of the formation, so directs erosion as to produce a series of small cuestas and vales with a general north and south trend and spaced a few yards apart east and west. The vales between the cuesta ridges are usually from three to fifteen feet deep and partially filled with mud or water.

The typical rock is dense, but distinctly granular and not vitreous. Some of the beds are very feldspathic, containing feldspar of composition ranging from albite to oligoclase, in addition to the granular quartz and occasional blades of muscovite. The feldspar is secondary and is of a composition rarely found in arkose. Its origin was discussed in the description of the preceding formation.

The massive quartzites extend as far as the Black River valley south of Solitudus Mountain where they disappear beneath the

glaciofluvial deposits in the valley. In the line of strike of the formation south of the river, however, is a quartz conglomerate which is a very probable equivalent of the quartzite farther north, although the river valley effectively bars any chance of tracing one into the other to prove this theory. The conglomerate is best exposed in a section due west of the kame between Amherst and Echo Lakes. The area of outcrop extends from the west shores of the above lakes, westward nearly to the crest of Dry Hill and from the head of Amherst Lake on the north nearly to the foot of Echo Lake on the south.

The conglomerate is composed of stretched pebbles of quartzite and granite gneiss in a schistose matrix composed of fine granular quartz and muscovite with accessory magnetite, zircon, tourmaline and secondary albite. The pebbles, or phenoclasts, vary in size from less than one-fourth inch in the finer phases of the formation to some eighteen by thirty-six inches in the coarsest phase near the base. The phenoclasts are greatly elongated in the plane of the bedding, which is oriented slightly west of north and dips east forty to fifty degrees. In cross-sections cut parallel to the strike and perpendicular to the bedding, the pebbles are lens shaped with the greatest dimension in the plane of the bedding and lesser dimension at right angles to it. The effect produced is as if the original pebbles were flattened from above and stretched from east to west. The gneiss pebbles were flattened and drawn out much more than those composed of quartzite. Sharply defined, rectangular, euhedral crystals of secondary albite are common in the micaceous matrix, and range in size from occasional ones one-half inch across to microscopic ones. Tiny octahedrons of magnetite are also present locally in the matrix.

The coarseness of the conglomerate decreases north, south and east from a spot at the base of the formation west of the foot of Amherst Lake. The prominent outcrops on the west shore of the latter lake, about midway of its length are composed of some of the upper beds which have but few pebbles and are like the matrix of the coarser phases. A rock closely resembling this upper phase is found north of the road leading west from the head of Amherst Lake and probably represents the northward extension of the normal conglomerate of Dry Hill but the area between is largely covered by a dense growth of underbrush and blackberry bushes so that a direct connection cannot be traced under present conditions. In the direction of Tyson the normal conglomerate becomes less coarse in texture and is finally replaced by a dark grey, graphitic, mica schist, exposed in the hillside pasture a few yards northwest of the foot of Echo Lake.

A lens-shaped mass of pure white dolomite is present in the conglomerate on Dry Hill three hundred feet above, and a few

hundred feet west of, the head of Echo Lake. The dolomite body is largely under cover, but is at least two hundred feet long, north and south, and fifteen feet thick near the middle of the outcrop, where a small quarry was opened and rock extracted for "burning" in a kiln a few yards away. The rock is very similar to that in the large bed to the north of Plymouth Notch. The shape of the body is probably due in part to squeezing during metamorphism as well as to the original shape of the mass of sediment, for the lens is oriented in the same position as the stretched pebbles in the surrounding conglomerate. The association of dolomite and conglomerate or coarse, pebbly quartzite is evident in all the important beds of dolomite in Plymouth and is believed to be unusual in that the conditions of sedimentation of the two rock types are usually considered to be dissimilar.

A second lens, evidently aligned with the above, is mapped by Dale¹ near the head of Amherst Lake in the northern part of the conglomerate area, but this was not found by the writer.

To return to the Mount Morgan section, the stratum overlying the massive quartzite is a bed of dark grey, carbonaceous dolomite, less than a yard in thickness. The dark rock is cut by narrow irregular bands and blotches of white dolomite apparently representing former fractures healed by the recrystallization of secondary dolomite in the seams. The dolomite horizon persists southward from the 1650 feet level on the Bridgewater-Plymouth line on Morgan Peak to a point three hundred and fifty yards east of Plymouth Lake, midway of the lake from north to south. The line of outcrop of the bed then turns slightly eastward up into a shallow valley and at the same time the bed thickens and changes in character to a pure white dolomite which outcrops in a widening belt past Grass Pond as far as Plymouth Notch where the kame deposits cover the formation. Several quarries were formerly operated in the white dolomite and a considerable quantity of rock extracted for roasting in nearby kilns.

The section below the upper quartzites on East Mountain is practically all covered by glacial deposits. Three beds of dolomite are exposed beside the road east from Moore's Ponds, south of Plymouth Village. Rock from the upper beds was quarried and roasted in nearby kilns, but the lower one is intruded by vein quartz to such an extent as to render it worthless. The relation of these dolomite beds to the other formations in the vicinity is completely obscured by surrounding cover, but they seem most probably to be referred to the horizon of dolomite mentioned as extending from Mount Morgan to Plymouth Notch.

It is probable that a bed of dolomite on the east side of Amherst Lake also belongs to this same horizon, both from the

¹ Dale, T. N., U. S. G. S. Bull. 589, p. 29.

fact that its position is almost exactly in the trend line of the dolomites farther north and also because it contains a carbonaceous bed, in common with the bed on Morgan Peak, a feature of no other stratum of dolomite in town. This bed of dolomite occurs in a laminated quartzite and extends from the head of Amherst Lake to at least as far as the junction of the road on the east side of the lake with the road branching off to Plymouth Five Corners. A marble quarry (Scott Quarry) was opened on the bed, about one hundred yards east of the head of Amherst Lake, and about fifty feet of dolomite is exposed. The rock from one unusual bed about three feet thick was the main object of quarrying. This is apparently an intraformational conglomerate (or possibly breccia) consisting of subangular phenoclasts of white dolomite in a matrix of dark grey carbonaceous dolomite and forms a strikingly mottled rock. The stratum is between two larger beds of white dolomite. The grey and white mottled rock was used as an interior building stone but owing to the prevalence of joints, large blocks were difficult to obtain and quarrying was abandoned many years ago. Two kilns were built to utilize the quarry waste for producing quick-lime.

UPPER QUARTZITE

The uppermost distinct formation of the group in the Morgan Peak section, in northern Plymouth, is a dark brown or black, plicated, quartzose mica schist. This rock somewhat resembles the overlying Pinney Hollow Schist in structure and texture, but is much less chloritic and in some places contains so much fine black coloring matter as to resemble a true phyllite. The rock, when exposed transverse to the schistosity, shows many fine laminae composed alternately of granular quartz and mica. The schist has very evidently yielded to pressure, for it is intensely wrinkled and folded in small isoclines in most of the section. The thickness, which is about three hundred feet on Morgan Peak, is probably augmented by this crumpling, and the thickness is somewhat less near Grass Pond farther south. The formation can be traced only as far as the same deposits in the vicinity of Plymouth Notch, where it is covered.

The section immediately underlying the Pinney Hollow Schist in the region east of Plymouth Notch, is quite different from that described above. On the west side of the crest of Wood Peak quartzites and phyllite outcrop between two areas of the Pinney Hollow Schist, and these can be traced southward along the eastern border of the "older Cambrian" group for about three miles, to Blueberry Mountain, where the character of the formation changes. The quartzites on Wood Peak and East Mountain are of two principal types, interbedded; a pale

brown or buff-colored variety with a slaty cleavage, and a grey or pale brown massive variety in beds about two feet thick. At the base of the Pinney Hollow Schist, and above the quartzites, is a few feet of phyllite overlying a bed of light grey dolomite about three feet thick and which outcrops between the Pinney Hollow road and Blueberry Mountain. The dolomite has been explored by trenching on the Lynde farm, on the south side of the road from Moore's Ponds to Plymouth Five Corners, and for a distance of about two hundred yards along the strike the bed has been laid bare. A trial kiln of the rock from this bed was roasted, but very little was done to exploit the deposit.

In the region south of Solitudus Mountain, the Pinney Hollow Schist is underlain by a very thin-bedded quartzite or quartzose schist which extends west to the Black River, and overlies the conglomerate on the east side of Dry Hill. The rock of this section has essentially the same mineral composition throughout, but the rock structure varies locally from a much plicated, crumpled schistose type, as that on the south slope of Solitudus Mountain, to a type with excellently developed slaty cleavage as that on the east slope of the hill east of Tyson.

THE PINNEY HOLLOW SCHIST

During the preliminary examination of the rocks of Plymouth, the formation herein named and described as the Pinney Hollow Schist was first examined at several excellent outcrops a few yards east of West Bridgewater village. Subsequently it was found that the formation was much more typically exposed in Pinney Hollow from the Pinney Hollow School westward nearly to Plymouth Village, and it was consequently named from that locality.

The formation is limited above by the Ottauquechee Phyllite and below by the "older Cambrian" brown quartzite or dark quartz-mica schist. Little variation was noted within the formation from western Bridgewater to southern Plymouth, and it is apparently a persistent and well-defined lithologic unit in this region. The thickness of the formation is variable, but in much of its exposure in Plymouth, is in the order of magnitude of 3500 feet. This may, however, be too large, since folding and thrusting has caused local thickening.

The rock is consistently a pale green quartz-chlorite-mica schist. Secondary movements, following those which induced schistosity, have often resulted in the formation of an incipient, poorly developed, slip cleavage inclined at about eighty degrees to the schistosity. Practically no indication of bedding is present in the schist except at the contact with the overlying and underlying formations. At these horizons the principal schistosity is

clearly parallel with the bedding, and inasmuch as the other formations of this part of the section all show many evidences of similar relation of schistosity to bedding throughout, it is reasonable to assume that the plane of schistosity is likewise approximately the plane of bedding in the Pinney Hollow Schist. The schist was, however, obviously non-competent to deformation. Minor zones of shearing and thrusting are common especially in that part of the formation having the greatest apparent thickness, *i.e.*, the part of the belt of outcrop which has the greatest width. The development of the secondary slip cleavage is likewise more or less confined to this part of the belt of outcrop and the schist is more distinctly platy or with slaty cleavage in other parts of

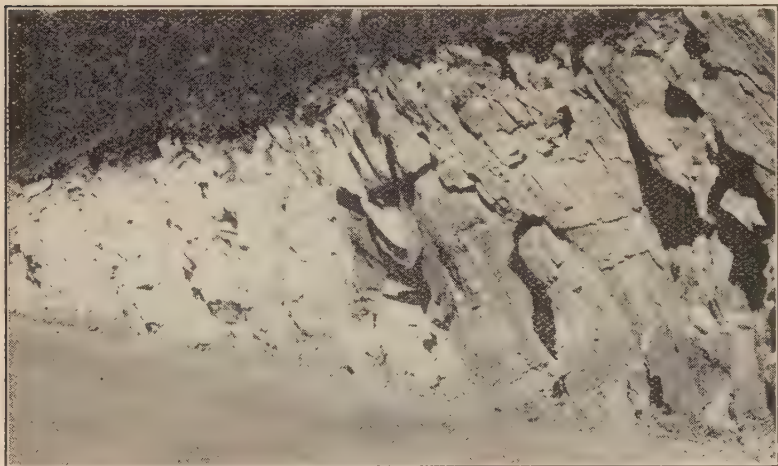


FIGURE 6.—Pinney Hollow Schist, West Bridgewater. Note the small wrinkles showing partially developed cleavage normal to the schistosity.

the belt. The Pinney Hollow Schist was observed in Ludlow to the south of Plymouth and in Stockbridge to the north, in both places quite similar to the rock in Plymouth.

Megascopically, the typical Pinney Hollow Schist is pale green and thinly laminated, often with minute crenulations, in the general plane of schistosity, passing into lines of slip cleavage. Distinct layers of quartz and the micaceous minerals, chlorite and sericite, visible and magnetite grains are often of sufficient size to be recognized. Other visible accessory minerals are rare.

At one locality in Plymouth on "Blueberry Hill" east of the head of Amherst Lake and near the base of the formation, a few outcrops showed staurolite, cyanite and magnetite developed as metacrysts in the otherwise normal schist. This porphyritic

phase is very local in occurrence and is undoubtedly due to metamorphism at a higher temperature than that affecting the normal schist. No intrusives were found in place nearby, but granite blocks are present in the general vicinity and it seems probable that intrusions may be responsible for this special phase, although the exact conditions are not known. The staurolite occurs as well-defined crystals about four millimeters in cross-section and showing the characteristic combination of prism and *b* pinacoid. Magnetite is very abundant in the form of small octahedrons about one millimeter across and the cyanite is less common, as stubby nearly rectangular crystals exhibiting two excellent cleavages nearly at right angles. Both the staurolite and cyanite are black and show abundant small carbonaceous inclusions with definite arrangement in the crystals.

A second uncommon rock type found in the Pinney Hollow Schist was a limestone outcropping in a small gulch beside the north raise of "Foxes' Mine" in Plymouth. The limestone is stratigraphically very near the top of the formation and occurs in the schist as small lenses only a few inches across. The rock is very impure and contains many small patches of pyrite, probably mineralization from the same solutions which produced the nearby gold-quartz veins. The extremely local distribution of the limestone makes it of very little stratigraphical importance in this case.

Microscopically, the typical Pinney Hollow Schist shows very little more than can be seen by the unaided eye. The lamination is of the order of magnitude of one millimeter or less. Quartz is abundant as anhedral grains about one-tenth of a millimeter in diameter. The grains are very even in size and have obviously been granulated, often showing strained extinction under crossed nicols. Occasional inclusions of tiny flakes of chlorite or sericite or grains of magnetite were noted, but in general the quartz is clear. Chlorite with sericite or muscovite is abundant in intimate mixture of small flakes having a parallel orientation and forming laminae between the laminae of quartz grains. Magnetite is abundant throughout, as very small grains and patches elongated in the plane of schistosity. Tourmaline occurs as occasional small pleochroic crystals similar to those observed in the Bethel, Missisquoi and other schists of the region. More rarely zircon is present as primary, rounded, clastic grains and often forms pleochroic halos in the chlorite. Irregular patches of calcite and crystals of garnet and apatite are still less common as accessory minerals.

Small veinlets of granulated vein quartz are common throughout the schist and in several places are very abundant, as on Morgan Peak on the Plymouth-Bridgewater line. The quartz does not, however, take the form of the lens-shaped masses

so common in the younger Bethel Schist. The intrusive relation of the quartz is abundantly illustrated by cross-cutting veins. The only other intrusive found in the Pinney Hollow Schist was a granite, which will be described in detail in another part of this report.

THE OTTAUQUECHEE PHYLLITE AND QUARTZITE

The group of rocks overlying the Pinney Hollow Schist has heretofore never received recognition as a distinct formation, but because of its extensive outcrop in Bridgewater and northern Plymouth, it is considered advisable to name and define it at this

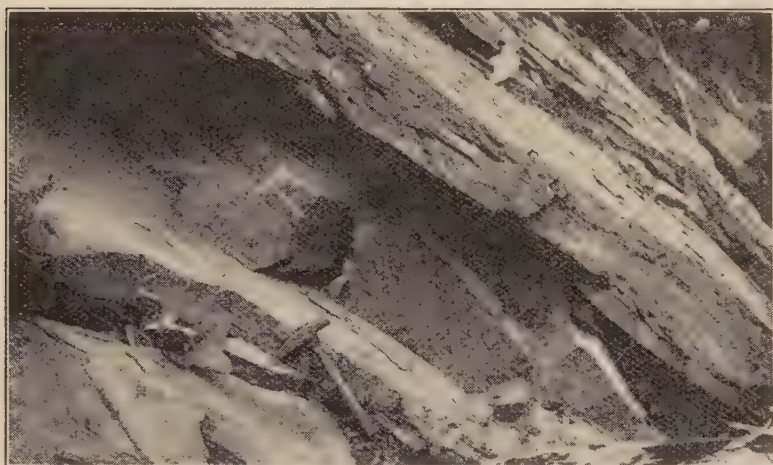


FIGURE 7.—Ottauquechee Phyllite above, Quartzite below.

time. The most typical exposures are found in the Ottauquechee River valley about halfway between West Bridgewater and Bridgewater Corners, and consequently it is proposed to name the formation after this stream. The formation is limited above by a quartz-chlorite-mica schist (the Bethel formation) and grades into the latter through a transition zone about two hundred feet wide. This zone is made up of small beds composed alternately of phyllite and chlorite schist. The exact contact of the Ottauquechee with the underlying Pinney Hollow Schist was not found, free of cover, at any point, but could be located within a few feet at several localities and is evidently a sharp contact, or one with a very narrow transition zone at the most. Two rock types in intimate association are typical of this formation, a massive, slate-grey quartzite and a dark grey or black phyllite. These

are in distinct contrast with the green schists above and below, *i.e.*, to the east and west, and are readily distinguished from them. The formation outcrops in a north-south belt, from one to one and a half miles wide, and is conformable to the underlying Pinney Hollow Schist.

The quartzite occurs in sharply defined beds from a few inches to ten feet in thickness, interstratified with the phyllite which makes up the major part of the formation. Veinlets of granulated white quartz, from one-half inch to two inches in width, are very common in the quartzite and strike a sharp color contrast with the dark rock. The veinlets are clearly cross-cutting in many instances and are altered vein-quartz intrusives. Stringers of vein-quartz are also present in the phyllite but are very irregular in outline, in direct contrast to the veins in the quartzite which have relatively straight, parallel walls. The veins in the quartzite are of such uniform distribution and persistent occurrence as to be characteristic of the formation everywhere. The quartzite is composed of two essential substances: Granulated quartz and black coloring matter. The latter is concentrated in different proportions in successive small layers so that much of the rock is laminated and the laminæ, in the order of one millimeter in thickness, range in color from pale grey to dark slate grey. Sericite and pyrite are present locally, in small quantities. The rock, at some places, has a very imperfect parting parallel with the bedding, but is usually massive. A system of jointing parallel with the strike and at right angles to the bedding, is everywhere strongly developed and occasionally a second system is present, oriented perpendicular to the strike in the vertical plane. The quartzite beds are very resistant to erosion, as compared with the associated phyllite, and appear in relief as small ridges at the more exposed outcrops. The jointing, however, has aided the reduction of the beds to small blocks and these, a foot or more in cross-section, are very common in the glacial drift of the region.

The phyllite of the Ottauquechee formation is a black, fine-grained, slightly micaceous schist with distinctly platy parting. The phyllite, as a rock type, is very uniform in appearance throughout the entire belt of outcrop. The essential minerals are quartz and sericite with black, carbonaceous coloring matter.

Light colored sandy or micaceous layers a few millimeters thick are occasionally present in the phyllite and in southern Plymouth beds of light colored chlorite-mica schists and micaceous quartzites appear in considerable numbers. The appearance of the formation in the southern section is thus in contrast with that in Bridgewater, since the phyllite is there unaccompanied by other beds than the characteristic grey quartzite. There is thus a change in the lithology of the formation from north to south along the strike and this is quite apparently due to an original difference

in sedimentation. Many of the beds of the southern section bear a superficial resemblance, lithologically, to beds in the younger Missisquoi formation, but are quite obviously in no way related to them. Near "Plymouth Kingdom" a few lenses of siderite and associated pyrite, chalcopyrite, and quartz veinlets have been found in the phyllite and prospected for iron ore. It is very questionable whether these represent altered primary sediments and they are believed by the writer to be the product of the secondary introduction of these minerals into the country schist.

The phyllite and characteristically associated grey quartzite is believed to represent deposits of carbonaceous shale and sandstone in the northern part of the belt, grading southward into more sandy and less carbonaceous facies.

BETHEL SCHIST

The Bethel Schist was named by Richardson¹ in 1924 and briefly described by him at that time. The same author had previously called that formation by the group name the "Hydromica Schists" but this name, like the corresponding "Talcose Schist" of Hitchcock which included the Bethel Schist among several others, is unsatisfactory because the nature of the name leads to confusion with other schists of similar lithology but of different age and origin.

The continuity of this formation from its type locality in the western part of the town of Bethel to the Plymouth-Bridgewater area was established in the field seasons 1925-26 and the formation traced as far south as the Plymouth-Ludlow line. The lithology varies somewhat along the strike, but on the whole the formation is a well-defined unit bounded by the Ottauquechee Phyllite on the west and by the Missisquoi group of schists on the east. The nature of the contact between the Bethel Schist and the Ottauquechee is especially well shown in the series of exposures on the hillside north of the Ottauquechee River, about two miles west of Bridgewater Corners. At this locality the interbedding of the phyllite and mica schist is clearly shown over a zone of about one hundred yards width across the strike.

Richardson² has described the Bethel Schist as

" . . . fine grained, greenish, schistose, highly metamorphosed sedimentary rocks which are more or less intimately associated with chlorite. These schists are, furthermore, characterized by numerous lenses, or eyes, and stringers of granular quartz."

This generalized description applies very well to the formation as it appears in the Bridgewater-Plymouth area. The rock

¹ Richardson, C. H., Rpt. Vermont State Geologist, Vol. XIV, 1924, pp. 82-83.

² *Ibid.*

is a green-grey, quartz-chlorite-muscovite schist, locally garnetiferous, but with few other important accessory minerals.

Quartz, as small (one-third millimeter), angular, anhedral grains segregated in layers one millimeter or less in thickness, makes up at least one-half of the rock. Between the quartz laminæ are layers of the micaceous minerals, chlorite and muscovite. The latter, mostly in the form of sericite, occurs as an intimate mixture of tiny shreds with occasional patches of light green, clear chlorite up to one-half millimeter in diameter and laths of muscovite of the same order of magnitude. The orientation of the tiny flakes of micaceous minerals, parallel to the coarser laminæ of quartz and mica, gives the rock its schistosity. The most common persistent accessory mineral is magnetite in grains less than one-half millimeter across and usually with anhedral form, although some of the grains are subhedral indicating partially formed octahedrons. The mineral is readily attracted to a magnet and is thus probably magnetite although the presence of titanite as occasional cloudy grains suggests that some ilmenite may be present with the magnetite. Microscopic prisms of tourmaline and less frequent rounded zircons are scattered through the schist. Garnets are locally abundant as in the section exposed along the Ottauquechee, just west of Bridgewater Corners, where they make up fully one-tenth of the rock. The garnets are dark brown (almandite?) and occur as imperfect dodecahedrons, usually less than one centimeter in diameter. Biotite is occasionally present, although not in noticeable quantities in the formation as a whole.

In addition to the finely granular quartz in the laminæ, small quartz lenses are very common in the Bethel Schist. These lenses, as they appear on the surface, average about six inches long and two inches wide at the widest part, tapering off to a point at either end. They are oriented with the longest dimension parallel with the strike of the enclosing schist, *i.e.*, approximately north and south. The third dimension shows that the mass is usually greatly elongated parallel with the dip of the schistosity, so as to form a columnar mass with lens-shaped cross-section.

Although these masses are very common in all parts of the formation, often several to the square yard, their general irregularity of distribution in space and occasional presence of a cross-cutting stringer of what seems to be the same material, suggests an intrusive origin and that these represent the remains of numerous quartz veins intruded prior to, or during, the final metamorphism of the region. Two other modes of origin have been suggested: That they represent metamorphosed pebbles of vein quartz or quartzite, and that they originated by recrystallization and segregation of quartz in the process of metamorphism of the

original shale. Neither of the two latter theories explain the observed facts as well as that advocated above.

THE MISSISQUOI GROUP

The term Missisquoi Group, as used by Richardson, is assumed to include all the metamorphosed sedimentary formations between the base of the Ordovician formations and the top of the Bethel Schist, in central Vermont. This term was introduced by the above author¹ in 1918. The name Missisquoi has unfortunately since been used by Kieth and Raymond² to designate an entirely different formation, of Cambrian age, found near Highgate Falls, Vermont. It must be made clear at the outset that these formations are not in any way related. The name is taken from that of the Missisquoi or Missisco River which rises in the town of Lowell in northern Vermont and flows northward into Canada, later swinging south again into Vermont and emptying into Lake Champlain.

The age of this formation, or group of formations, has been referred to the upper Cambrian by Richardson, in the course of his work in central Vermont. But it must be emphasized that the age of the Missisquoi, in Vermont, has not been determined on the evidence of fossils.

"The relative age of these formations has been determined by their stratigraphic position, continuity, and lithological characteristics. They are unquestionably pre-Ordovician for they furnish the pebbles for the Irasburg Conglomerate which lies at the base of the Ordovician series in eastern Vermont."³

Thus, although it seems highly probable that these are of late Cambrian age, no direct proof can be offered. As will be pointed out below, the formation unconformably overlying the Missisquoi is Lower Ordovician in age.

Although in a broad way the formations which go to make up the Missisquoi Group have much in common, they differ considerably in minor details. Richardson has subdivided the group into two parts, a sericite schist and a sericitic quartzite. In addition to these, local occurrences of phyllite, chlorite schist and hornblende schist are also cited. The Missisquoi as best exposed in Bridgewater does not lend itself to such a subdivision, but may be resolved into a micaceous quartzite which makes up the most of the upper half (similar to that of Richardson) and a series of thin-bedded schists of considerable variety, making up the lower part.

¹ Richardson, C. H., Rpt. Vermont State Geologist, 1917-18, p. 138.

² Raymond, P., Rpt. Vermont State Geologist, 1923-24, p. 137.

³ Richardson, C. H., Rpt. Vermont State Geologist, 1923-24, p. 101.

THE UPPER MISSISQUOI

The upper Missisquoi quartzite is well exposed on Richmond Hill, Southgate Mountain, and Cobb Hill in Bridgewater, where large outcrops smoothed by glacial erosion are common. Throughout most of this section, but particularly in the vicinity of Bridgewater Village, numerous narrow zones of hornblendic rock are present in the quartzite and sometimes form a considerable part of the whole, but for the most part the formation is a fairly uniform quartz-mica schist.

Much of the quartzite bears a superficial resemblance to gneiss in the arrangement of light and dark minerals, particularly where the rock has been subjected to isoclinal folding on a small scale, but feldspars are rare or absent in most specimens and the chief minerals are quartz, white mica and biotite, with garnet forming an important constituent at some localities. The presence of hornblende in the upper Missisquoi is a local feature of the formation near Bridgewater Village. The hornblendic rock occurs both as dike-like bands having well-defined borders and as bands which show a gradual decrease in the proportion of hornblende from the center outward into apparently normal country rock. The presence of the hornblendic rock is interpreted as being due to the presence of mafic intrusives close beneath the surface of this area and a consequent higher grade of metamorphism, and introduction of mafic material, in the quartzite.

A study of thin sections of the typical upper Missisquoi shows the quartz to be the predominant mineral and it comprises about four-fifths of the rock. The micaceous minerals are second in importance. Biotite and muscovite occur as isolated laths scattered through the rock and chlorite is present as irregular pale green patches associated with the biotite. Occasional magnetite grains are associated with the chlorite. Tourmaline is sparingly present as short, thick, well-rounded prisms. The quartz of the ground mass is granulated and appears as a mosaic of uniformly small, interlocking, angular grains cut by all the other minerals with the exception of the tourmaline which is apparently present as primary clastic grains. The parallel orientation of the micaceous minerals serves to give the rock its imperfect schistosity.

THE LOWER MISSISQUOI GROUP

The varied schists comprising the lower portion of the Missisquoi Group are best exposed in the bed of the north branch of the Ottauquechee River, from the northeast base of Freestone Hill westward through Chatauguay nearly to the Sherburne town line. The section here uncovered is nearly continuous across the strike, for a distance of about three miles. In general the indi-

vidual beds of schist are but a few feet in thickness and adjoining beds are often of extremely contrasting lithology. The considerable breadth of the exposed section and the enormous number of rock varieties displayed, renders impractical any attempt to describe them in detail. It is the intention of the writer to describe below some of the more typical and abundant rock types, in order to convey an impression as to the general nature of the group. Some of the more unique beds can be traced for a considerable distance along the strike, but none is sufficiently persistent to serve as a distinct horizon marker and thus exact correlation of a section in one part of the town with a detached section in another, is highly conjectural at best. A careful study of the area would very probably yield information which could be used in correlation, but such a study would be quite out of place at the present time when much remains to be done in delimiting and mapping the broader units of the section in nearby areas.

The general mineral assemblage of the lower Missisquoi is well defined and consistent throughout the group, although adjoining beds may vary in their individual mineral composition. The four characteristic minerals are quartz, garnet, biotite and sericite. A few other minerals are present in lesser amounts, viz., chlorite, magnetite, hornblende, pyrite and muscovite. Still others are occasionally present, although not noticeable in a megascopic examination. Quartz is the most persistent mineral throughout and very often is found to be the major constituent of individual strata. Sericite, the next most *noticeable* mineral, is nearly always present on planes of parting in the schists and imparts a silvery luster to fresh surfaces. Garnet is very abundant and is usually associated with biotite and a minor proportion of chlorite. It is of interest to note at this point that Dr. Richardson, in verbal communication with the writer, has commented upon the presence of much biotite in the Missisquoi of Bridgewater, as contrasted with the lack of this mineral in rocks of the same group to the northward. This is probably due to a difference in environment during metamorphism and a reaction of earlier sericite with chlorite to form the biotite.

The majority of the lower Missisquoi rocks fall in one of four rock types: garnetiferous mica schist, micaceous quartzite, carbonaceous mica schist and chlorite schist, although the latter is considered in most instances to represent intrusives rather than true sedimentary rocks of this group. The number of individual variations within these main types is legion.

The quartzites are never very pure, but always contain admixtures of biotite, sericite and sometimes garnet. They are often finely laminated both with respect to color and distribution of minerals. In general the parting is ill defined, since the micaceous minerals are neither present in sufficient quantity, nor

are they sufficiently segregated, to produce well-defined planes of weakness. The best exposures of the quartzite phase of the lower Missisquoi are found in a zone about a quarter of a mile east of the upper contact of the Bethel Schist. In this zone are the outcrops west of Chatauguay, lower Dailey Hollow, west of Bridgewater Corners, and the western side of Hale Hollow.

The carbonaceous mica schist of the lower Missisquoi is found in isolated strata interbedded with the quartzites and chloritic schists, but is also found in a fairly well defined belt passing through Chatauguay, lower Dailey Hollow, Bridgewater Corners and Hale Hollow, following approximately the eastern line of outcrop of the quartzites mentioned above. Lithologically, the carbonaceous mica schist resembles the Ottauquechee Phyllite except that the parting is not as pronounced as in the latter, and garnets are occasionally present in addition to the essential quartz, sericite, and black coloring matter. Thin layers of light colored chlorite-sericite schist are sometimes present in the beds of black schist. The carbonaceous schist is interpreted as representing metamorphosed black shales with occasional interbedded sandy or non-carbonaceous, shaly layers.

Interbedded with the quartzites and carbonaceous schist are beds of garnet-sericite-chlorite schist of considerable variety. The usual color of this type of rock is greenish grey spotted with black biotite and brown or pink garnets. The ground mass of the rock is composed of granular quartz and poorly crystallized micaceous minerals, and is of quite uniform appearance in any one bed. No marked zone of outcrop of this rock is apparent, but it is quite as abundant, scattered through the group, as are the micaceous quartzites or the carbonaceous schist.

THE WAITS RIVER AND RANDOLPH FORMATIONS

The Waits River Limestone and Randolph Phyllite, of central Vermont, have been the subject of an extensive study by Dr. C. H. Richardson, of Syracuse University, during a period of more than twenty years. From near Lake Memphremagog in Canada, where the beds contain fossils of Middle Ordovician age, the beds have been traced southward in a continuous belt as far as the area at present under discussion. At several localities in Vermont, fossils, mostly graptolites, have been found in the metamorphosed shales and limestones and in all cases these indicate an Ordovician age for the formations.

The locality in the Ordovician belt which has furnished the most extensive graptolite fauna is the Castle Brook section, Magog, P. Q. The species found there have been listed by

Dawson,¹ Gurley,² Richardson,³ and Ruedemann.⁴ Ruedemann, whose work is the latest of the four and generally accepted as authoritative, places the age of this fauna as just below the Utica, *i.e.*, upper Middle Ordovician. The same author places the age of the slate at Montpelier, Vermont, as Beekmantown upon his identification of *Tetragraptus amii* among specimens found by C. H. Richardson at that locality. The formation in Northfield has likewise yielded a graptolite, *Phyllograptus angustifolius*, of Beekmantown age. At most of the other Vermont localities which have furnished graptolites, the rocks have been so metamorphosed as to render the determination of species impossible and in most cases even the genus is indeterminate. This is particularly true in the towns just north of the area under discussion. But while the exact age of the formations is often in question, it remains certain that they are, at least, definitely Ordovician.

The base of the Ordovician, in some parts of central Vermont, is marked by a basal conglomerate, the Irasburg Conglomerate, but no evidence of this rock was found in Bridgewater. The exact contact of the Randolph Phyllite and the underlying formation was not observed at any locality, but was determined within fifteen feet at one point and no marked change in lithology was evident in the phyllite near the contact. The underlying formation is the upper Missisquoi quartzite and is quite unlike the phyllite, so that no difficulty is encountered in determining the lower or western boundary of the Ordovician section.

The Ordovician rocks in Bridgewater may be subdivided into two types according to lithological characteristics: The phyllite named the Randolph Phyllite by C. H. Richardson, in 1924, and a formation which ranges in composition, locally, from a siliceous-calcite marble to a calcareous quartzite and is a phase of Richardson's Waits River Limestone. The phyllite is classed by the same author as a member of the Memphremagog Group of metamorphosed shales. It must be strongly emphasized that these different formation names do not necessarily imply different ages for the two rock types, but simply a difference in lithology. The phyllite and limestone are of the same general age, as far as their outcrop in Bridgewater is concerned, for they appear interstratified in thin beds at many localities.

The phyllite is a dark grey, strongly foliated, graphitic looking, mica schist which parts readily into irregular fragments parallel to the imperfect schistosity. In addition to the essential quartz, mica, and dark coloring matter, the most abundant accessory mineral is garnet, which often makes up more than a third of the volume of the rock. The garnet crystals are from one to

¹ Dawson, G. M., Geol. Sur. Can. Rpt., Vol. VII, 1894, Apen. J, p. 133.

² Gurley, R. R., Jour. Geol., Vol. IV, 1896, pp. 294-301.

³ Richardson, C. H., Rpt. Vermont State Geologist, 1901-02, p. 97.

⁴ Ruedemann, R., N. Y. St. Mus. Memoir No. 1, Part 2, 1908, p. 29.

two millimeters in cross-section and are evenly distributed through the phyllite. The mica laminæ curve about the garnets and cause the uneven "fish scale" appearance of the rock surface along a plane of parting. Occasional biotite crystals are present, but are not sufficiently abundant to be characteristic of the formation. Pyrite is present as small scattered cubes often much weathered to limonite. The surface of the phyllite outcrops is black, often with numerous rusty streaks and bands of dull brown and grey, which represent original bedding. These bands usually form a considerable angle with the schistosity and are nearly vertical.

The limestone is a uniformly slate grey massive rock with no fixed lines of parting. The essential components are calcite and quartz, both recrystallized from their original form, and black carbonaceous coloring matter evenly distributed through the rock. Sericite is present as scattered shreds but in insufficient amount to produce schistose parting. Quartz grains are so abundant in some parts of the formation as to make a quartzite rather than a limestone, but calcite is consistently present and it seems advisable to refer to the formation as a whole as a limestone.

The limestone weathers readily to a *porous*, seal brown rock on the exposed surfaces and is unique in appearance among the other rocks of the area. Bedding is rarely shown in the limestone itself and is practically indeterminate except at the contacts with strata of phyllite.

On the geological map of Bridgewater the areas mapped as the Randolph and Waits River formations are divided arbitrarily so that the latter contains more than half limestone and the former includes more than half phyllite, but it must be made clear that no *sharp* subdivision along such lines is possible. The phyllite is preponderant at the base of the Ordovician and becomes decreasingly abundant in the younger strata which are composed of great thicknesses of limestone with very little phyllite.

No attempt can be made to estimate the thickness of the Ordovician section exposed in Bridgewater, because of the intense isoclinal folding everywhere present. Folding is much more intense in the non-competent phyllite and the bedding planes are usually either vertical or dipping at high angles east or west. There is often overturning of the small folds from east to west and many of them, only a few feet across, pitch northward and die away within a few feet along the strike. The strike is necessarily somewhat variable, but is consistently near N 10° E.

AMPHIBOLITES

Intrusive into the schists of the Missisquoi and immediately underlying formations are several stocks and dikes of metamorphosed igneous rock which, particularly on the weathered sur-

face, closely resembles a diorite. An examination of thin sections shows the amphibole of the rock to be in the form of uraltite, fibrous secondary hornblende, indicating that the rock is an amphibolite or more exactly an "epidotamphibolite"¹ since epidote is present in considerable quantities. Schistosity is but slightly developed in the most typical phase of the rock so that the name hornblende schist is scarcely applicable.

The major exposures of amphibolite are shown on the geological map of Bridgewater. The most important stock is that forming the peak of Bull Hill one and one-half miles north of Chatauguay, in the northwest corner of the town. The shape is approximately an oval 1,000 yards long and 500 yards wide, with the longer dimension north and south. At the southern base of the hill near the Chatauguay-Barnard road the contact of the intrusive rock with the country rock, which is here a garnetiferous mica schist of the lower Missisquoi Series, is visible for several yards along a small brook. Contact metamorphism attendant on the intrusion was apparently slight for no alteration is noticeable in the country schist except in a zone about a yard wide of somewhat finer texture adjacent to the contact. Slight textural variations are evident throughout the intrusive so that some areas are relatively coarse, with crystals up to one-half inch across, although most of the amphibolite is of fine grain (.25 inch) and with a preponderance of dark minerals.

The cross-cutting relation of the amphibolite to the country rock is very clearly shown at the contact at the base of Bull Hill mentioned above. The contact here cuts across the strike of the bedding in the garnetiferous sericite schist at angles up to ninety degrees. The east and west borders of the amphibolite body are approximately parallel to the strike of the country rock. A dike of material which is evidently a fine-grained phase of the amphibolite outcrops in the brook beside the Chatauguay-Barnard road at an elevation of 1,800 feet, south and slightly east of the main stock. The dike is thirty to forty feet wide and can be traced northwestward into the main body in a distance of about one hundred yards.

The coarsest phase of the intrusive was found near the crest of Bull Hill on the north side. This rock contained comparatively fresh feldspars, up to five mm. in cross-section, enclosed in fine-grained fibrous amphibole. No other minerals were recognized in hand specimens. The rock when examined in thin sections with the aid of the microscope, showed the following minerals: Abundant cloudy crystals of *albite* of composition about $\text{Ab}_{92}\text{An}_8$ as determined from the maximum extinction angles of 16 and index refraction less than balsam; abundant hornblende,

¹ Osann, Dr. A., *Elemente der Gesteinslehre*, 2 Hälfte, p. 448, Stuttgart, 1923.

probably pargasite, in the form of long laths and bundles of fibers cutting everything except epidote and apatite; biotite common as euhedral plates and laths, sometimes fresh but often altered to chlorite; epidote common as small irregular grains usually in contact with the feldspar; apatite abundant as small prisms up to 0.6 mm. long and 0.1 mm. in cross-section; quartz and magnetite as small anhedral grains interstitial to, or enclosed by, the other minerals.

Other specimens from Bull Hill, although of finer texture, have the same essential mineral composition as that described above, namely, plagioclase, uraltic hornblende and epidote. The additional accessory minerals calcite, titanite, zircon and tourmaline were noted in other specimens. Tourmaline was very abundant in the amphibolite at the exact crest of the hill and was present both as rosettes of fibers and as sheets about two inches thick composed of very fine fibers arranged transverse to the enclosing walls. Hand specimens of the latter material resemble charcoal in superficial appearance, except for a delicate silky sheen on a fresh surface.

The small stock mapped to the south of Chatauguay and that west of Bald Mountain in southern Bridgewater are essentially of the same composition as that of Bull Hill and also bear the same relation to the country rock. A small dike on the Bridgewater-Woodstock line in Curtis Hollow, several in Bridgewater Hollow and many others, too small to be mapped, scattered through the Missisquoi formation are similar in composition to the larger stocks and are probably genetically related to them. Microscopic examination of rock from the various bodies shows that they vary only in the relative proportions of the different minerals and not in the general assemblage.

These amphibolites are considered by the writer to represent recrystallized plutonic rocks which probably had the original composition of a diorite or a gabbro. The original mafic minerals, biotite and either amphibole or pyroxene, have been recrystallized to uraltic pargasite and chlorite while the original plagioclase has been altered to albite and strongly calcic epidote.

STEATITE

At least five separate areas of steatite are present in Bridgewater and Plymouth, but all except one have a very limited outcrop. All have been prospected for commercial soapstone or talc and the rocks show the same essential composition at each locality.

The most accessible outcrop, and one which may be considered as typical, is that at the southeast base of Freestone Hill, a few yards west of the road from Briggs to Chatauguay. The steatite here was formerly quarried for local use and fresh sur-

faces of the rock are well exposed. The steatite is limited to an approximately circular area about fifty yards in diameter, covered on the south and east by kame deposits and bounded on the north and west by sericitic quartzite of the Missisquoi formation. The rock in the central part of the body is composed almost wholly of two minerals: talc, comprising the major portion of the rock; and ankerite, often abundant as veinlets. Chlorite is present in minor amount. The talc is locally pure and well crystallized in pale green plates, but is most often present as the massive impure mineral.

Because of the presence of ankerite or dolomite in numerous veinlets, the rock is of little commercial value. These minerals cause difficulty in quarrying and trimming the rock because of their hardness and brittleness and also lessen its resistance to heat changes. The ankerite is of scientific interest, since it gives a clue to the origin of the steatite body. Ankerite is typically a product of the metamorphism of igneous rocks and in this case gives added proof to the indications yielded by the field occurrence, *i.e.*, cross-cutting relationship and marked lithologic dissimilarity to the surrounding rock, that this body was once an igneous intrusion. Although the soapstone most probably continues with depth, the small size of the outcrop, the numerous impurities present, and the distance from a railroad all combine to render commercial exploitation quite impractical except for an extremely local use on a small scale.

Two small outcrops of steatite are present on Bridgewater Hill about a mile and three-quarters east of West Bridgewater (see map). The steatite is here enclosed in the black phyllitic schist of the Ottauquechee formation. The best outcrop is situated about one hundred yards north of the McElroy farmhouse and has at one time been prospected for soapstone. The steatite body is very small, about fifteen feet in diameter and roughly circular, judged from the appearance of the prospect pit which is now nearly filled with water. Material from a dump beside the pit shows a better, much more uniform grade of rock than that in the body north of Briggs, but some carbonates are present and locally the rock is said to be "gritty." At this outcrop the country rock is typical black phyllite with some quartzite near by, quite different lithologically from the rock at the Briggs deposit. The second outcrop mentioned above is about a thousand yards south, slightly east of the first, and is in line with the latter along the trend of the bedding of the country rock. It is very similar to the first in all ways and needs no further comment. In this same general vicinity, near the top of Bridgewater Hill, a piece of asbestos with well-developed fibers one inch in length was found by Mr. Hesleton in a piece of float in a pasture. It is highly probable that this is to be found in place near by and

that the occurrence of asbestos is associated with the steatites or very closely related basic intrusions in the vicinity.

Two areas of steatite and associated rocks were found in Plymouth. A third area was mentioned by Hager in his report of the geology of Plymouth, but this could not be located by the writer. The largest body in the town outcrops in a long strip extending from the vicinity of Plymouth Five Corners southward for about two miles. The strip is about eight hundred feet wide near the northern end and becomes slightly narrower to the south. The country rock is the Ottauquechee phyllite and the intrusive cuts across the strike of the latter at a small angle (see map). The best exposure in this area is situated in the bed of a small brook, a few yards north of the "Five Corners." At this locality some exploration has been carried out by sinking a pit into the intrusive. The rock differs considerably from that at the Bridgewater localities in that much more chlorite is present, especially on the border of the intrusive. In the prospect pit a fibrous amphibole is abundant in irregular streaks and crystalline aggregates. The amphibole is tremolite rather than actinolite, because of the small iron content, *viz.*, 2.34 per cent FeO. A low content of water indicates that little alteration to talc has taken place. Most of the amphibole occurs in a massive, pale green rock composed of radiating bundles of short fibers, but some is distinctly asbestiform of a type often called "slip fiber," arranged in layers of overlapping fibers about six inches long, approximately parallel to the walls of the sheet. The fibers have little strength, owing to an excellent basal parting transverse to the prismatic needles of the mineral.

The amphibolite is of limited distribution in the center of the body and is surrounded by a zone of dark green, highly chloritic rock containing irregular lighter patches bearing a small proportion of talc with some ankerite and chalcopyrite. Near the border of the intrusive the rock is more chloritic and less talcose, but has no definite planes of schistosity and is quite unlike any other chloritic rocks in the region. The entire assemblage is much like other outcrops of talc-bearing rocks in Vermont, as described by E. C. Jacobs,¹ but the zones defined by him are not well developed in this case. The interior zone of carbonate-bearing talc, similar to that in the Bridgewater deposits, is noticeably absent. The tremolitic rock possibly represents the original nature of the intrusion, but is more probably a halfway step in the formation of talc by hydrothermal alteration of an original pyroxene or olivine-bearing rock.

In tracing the zone of outcrop from the "Five Corners" southward, the massive chlorite-talc rock was found to persist in

¹ Jacobs, E. C., Rpt. Vermont State Geologist, 1913-14, pp. 402-3.

a few scattered outcrops, and much float, for about two miles. A distinct outcrop of steatite with dolomite (or ankerite) very similar to those in Bridgewater crosses an east-west road 2600 yards south of the "Five Corners" and is a part of the same belt.

An area somewhat similar to that described above, appears in the extreme southeastern corner of Plymouth, in the Missisquoi formation. Like that at the "Five Corners," much of the rock is very chloritic, but at the north end of the area (see map) near "Plymouth Kingdom," a small patch of steatite was at one time exploited. The blocks of soapstone, after quarrying, were trimmed by a saw driven by water power from a nearby brook.

It is evident from the above that the writer considers the described deposits of steatite to be the product of metamorphism of plutonic rocks rich in magnesian minerals. This theory is also advocated by E. C. Jacobs,¹ C. H. Hitchcock,² J. A. Dresser,³ and M. E. Wilson⁴ for other similar or identical deposits in Vermont and the Eastern Townships of Quebec. These deposits are part of a series of steatite and serpentine outcrops extending along the eastern Appalachians from Gaspé to Georgia and are probably quite different in origin from those of Ontario or of western New York State. An excellent résumé of the present knowledge of the talc deposits of North America is given in the paper by Wilson, cited above, and comparison of the various origins proposed, may be obtained from that source. In the case of the deposits in Bridgewater and Plymouth, it may be briefly stated that there is no indication of the derivation of the talc from the metamorphism of a sedimentary dolomite, and the theory of origin from the hydrothermal alteration of a chloritic mica schist (originally sedimentary) is untenable, since the steatite is here found enclosed in black phyllite, carbonaceous quartzite, or sericitic garnetiferous quartzite, often with beds of varying lithology, all of which would probably have some noticeable effect on the final appearance of the steatite, if formed in this way.

The age of the steatite intrusions can not be determined with certainty, but is probably as suggested by Wilson (preceding citation, page 10) middle Paleozoic. Within the Bridgewater area the steatites were not found in the Ordovician rocks, but are present in the youngest Cambrian strata, and their degree of metamorphism is interpreted as indicating an age greater than Devonian. The writer was unable to find mention of a steatite body, in either Quebec or Vermont, which was found in rocks known to be Ordovician or younger, hence this may be taken as indica-

¹ Jacobs, E. C., *prec. cit.*, 1914.

² Hitchcock, C. H., *Jour. Geol.*, 1896, p. 58.

³ Dresser, J. A., *Can. Min. Inst. Trans.*, Vol. XII, 1909, p. 177.

⁴ Wilson, M. E., *Talc Deposits of Canada*, C. G. S. Ec. Geol. Series No. 2, 1926.

tion, although not a proof, of a pre-Ordovician, *i.e.*, a late Cambrian, age for the steatites.

GRANITE GNEISS OF DRY HILL

On Dry Hill northwest of Tyson, and west of Amherst Lake, an area of granite gneiss about a quarter of a mile wide and one and a half miles long forms the crest and northern spur of the hill. The area is bordered on the east by conglomerate and on other sides by a black, porphyritic, albite, mica schist. As far as could be determined, the area is isolated from any other bodies of gneiss in the vicinity and is confined to an elongated area of outcrop in the general line of strike of the enclosing rocks (see map). From the areal distribution and lithology of the gneiss, it is believed to be an igneous intrusion along a zone of weakness between the relatively competent conglomerate and the underlying schist. On the west slope of Solitudus Mountain north of the area of gneiss, a small sill of metamorphosed granitic material appears in the albitic schist and strongly suggests a connection with the gneiss across the valley, thereby strengthening the above hypothesis.

The problem of intrusion is vital in this case, since the granite gneiss bears a superficial resemblance to some of the pre-Cambrian gneisses in the Mount Holly Series. In detailed mineral composition, however, the Dry Hill gneiss does not coincide with the pre-Cambrian ones. It is evident that at first sight the gneiss might be considered as pre-Cambrian and the overlying conglomerate to be a true basal conglomerate of the Cambrian, but this is believed not to be the case since a complicated system of faults would be required to explain the observed relations on this hypothesis.

The typical gneiss is not distinctly banded, but is streaked with small discontinuous layers of chlorite and mica with rough parallel orientation. Some of the gneiss in the central portion of the outcrop shows augen structure on a very small scale. The minerals visible on microscopic examination are feldspar, apparently a potash feldspar, quartz, chlorite and white mica. Examination of the rock by aid of a microscope shows the common feldspar to be mostly microcline in anhedral grains up to 1.0 mm. in cross-section. Albite is occasionally present as clear, fresh crystals, and quartz is relatively abundant, likewise as clear anhedral grains. Chlorite is sufficiently abundant and persistent as to be classed as an essential mineral and is present both as large crystals and as small rounded blebs in the feldspar. Muscovite and magnetite are abundant accessories. The most notable contrasts be-

tween the minerals of this gneiss and the pre-Cambrian type are in the abundance of microcline and lack of epidote and apatite in the former.

Near the contact of the gneiss with the conglomerate on the east the grain of the gneiss is visibly finer and the rock less chloritic than in the center of the mass, and thus suggests an intrusive rather than erosional contact. This is further borne out by the fact that most of the boulders and pebbles in the base of the conglomerate are quartzite and not gneiss. The age of this gneiss is in question. The degree of metamorphism would suggest an early Paleozoic age, if the mode of origin of the mass has been correctly interpreted, and this represents an intrusion of granitic composition.

VEIN QUARTZ

Vein quartz and more rarely pegmatite, is very common in the metamorphosed Paleozoic sediments of Plymouth and Bridgewater and somewhat less abundant or less obvious in the pre-Cambrian rocks. The quartz has, in practically all cases, undergone obvious granulation and has been involved in the movements accompanying the metamorphism of the region. The quartz veinlets are absent from both the metamorphosed and unmetamorphosed igneous rocks, but are very abundant in the metamorphosed shales of the Pinney Hollow, Ottauquechee, and Bethel formations.

In most instances the vein quartz is intrusive in the planes of schistosity of the country rock, but is occasionally cross-cutting, particularly in the more massive types such as the grey quartzite associated with the Ottauquechee phyllite. The usual size of the quartz veins is small, two or three inches across, but occasional well-defined veins up to thirty inches, and irregular masses up to ten feet, across were observed. As contrasted with these maximum dimensions, many veinlets of microscopic size were also noted. Many of the bodies of quartz are lens shaped, as if distorted by movement, but it is very difficult to determine whether such structures are purely secondary or whether they are in part primary and determined by the structure of the rock into which they are intruded. The quartz lenses described in connection with the Bethel Schist are a case in point.

Orthoclase feldspar is rarely present with the granulated quartz as crystals up to an inch across and in the largest veins metallic sulphides and native gold are occasionally developed. The common sulphides are galena, chalcopyrite and pyrite, with the former most abundant.

PLYMOUTH GRANITE

The occurrence of granite on the south slope of Morrison Hill in Plymouth has been described by both Hager¹ and Dale². The outcrop is situated about one-half mile northwest of the Pinney Hollow road and an equal distance due west of the Pinney Hollow schoolhouse, east of the road to the abandoned Morrison farm at about the 1,500 foot contour level.

The timber has been recently cut from the hillside in the vicinity of the granite and a dense growth of underbrush obscures the limits of the outcrop but the shape is approximately that of a lens, at least 500 feet long and 100 feet wide at the widest part with a vertical exposure of about thirty feet. The igneous intrusion entered along the plane of schistosity of the Pinney Hollow Schist so that it is essentially a concordant body with very little cross-cutting along the visible contact. The country rock is well exposed in contact with the granite on the north, or upper side, of the lens. Several dikes of aplite about one foot wide extend at right angles from the intrusive a few feet into the country rock and in one spot stringers of the aplite surround small blocks of the schist. These dikes are apparently intruded along lines of tension jointing at the crest of the low arch of the upper side of the lens. A few aplite dikes were also found in the schist about 600 feet northwest of the main granite mass.

The intrusive is considered by T. N. Dale to be a quartz monzonite but according to recent practice in petrography would be considered as an albite granite or possibly a granodiorite or quartz diorite. It is, however, convenient to speak of the rock as a granite since it is a holocrystalline rock composed almost entirely of quartz and feldspar and with no mafic minerals. The essential composition, computed by the Rosiwal method, is: Quartz 30.3 per cent, albite 60.5 per cent, microcline 5.7 per cent, microperthite 1.6 per cent, muscovite 1.7 per cent, and apatite 0.1 per cent. In thin section the quartz is present as comparatively clear anhedral grains; the plagioclase (albite ranging to oligoclase) as anhedral grains considerably altered to sericite with some calcite and kaolinite; the microcline as anhedral grains showing little alteration; the microperthite as much altered grains with considerable sericite and kaolinite; the muscovite as well-defined laths interstitial to the quartz and feldspar; and apatite as occasional small euhedral prisms.

Hand specimens of the rock are white with no dark minerals. The feldspars are milky and the quartz colorless to pale blue making up a medium-grained (0.2 inch) rock of granitic texture.

¹Hitchcock, C. H. and E., Jr., and Hager, A. D., Rpt. Vermont State Geologist, Vol. II, 1861, pp. 740-741.

²Dale, T. N., Commercial Granites of New England, U. S. G. S. Bull. 738, pp. 160-161.

Resemblance to the Bethel granite of Bethel, Vermont, twenty miles north of Plymouth, is very marked.¹ At the border of the Plymouth intrusive the texture is very fine, approaching felsitic, and indicating marginal chilling. Contact metamorphism is almost absent; consisting as it does of the silicification of the adjoining mica schist for a distance of only two or three inches. This silicification destroys the schistosity of the country rock indicating metamorphism of the latter prior to the intrusion of the granite.

A dike of essentially the same material as the granite described above is located on the south slope of Soltudus Mountain in Plymouth, one mile south of the "Old Notch." The dike is about fifteen feet wide and may be traced as a line of subangular blocks, in a N 30° E direction, for several yards up the wooded hillside.

The dike rock has a composition: Quartz 26 per cent, albite 50.9 per cent, microcline 7.8 per cent, micropertite 7.1 per cent, muscovite 6.1 per cent and pyroxene (augite) 1.9 per cent. The most important differences between this rock and that previously described are in the greater proportion of potassic feldspar to albite and in the presence of a small amount of light colored pyroxene. The texture, size of grain, and color are all the same as those of the granite on Morrison Hill.

Numerous loose blocks of the same granite are present in the glacial drift in the amphitheater-like valley west of Blueberry Hill and southeast of Soltudus Mountain in Plymouth, about three-fourths of a mile east of the above-mentioned dike. No outcrop of granite was found in place in the vicinity.

The age of intrusion of similar Vermont granites has been placed as Devonian by several writers. Dale considers the age to be "probably the end of the Devonian or Carboniferous." Ells in writing of the granitic intrusives of the Eastern Townships of Quebec, just north of Vermont, advocates the theory that "it is probable that the age of the granites is not far from the close of the Silurian period."² The most accurate age which can be assigned from a study of field relations of granite and country rock in this part of Vermont, is post-Ordovician, for the granites cut rocks of Ordovician age. It seems reasonable, in view of the fact that no crushing or other sign of metamorphism is evident in the Plymouth granite that the age of intrusion is coincident with or slightly later than the orogenic movements of the Appalachian Revolution generally recognized as having taken place along the Green Mountain axis. On this line of reasoning the age could be put as late Paleozoic with reasonable cer-

¹ Dale, T. N., *Commercial Granite of New England*, U. S. G. S. Bull. 738, 1923, p. 156.

² Ells, R. W., *Ann. Rpt. G. S. Can.*, 1894, Part J, p. 69.

tainty, especially if the diabase dikes, which have been found to cut the granite at Bethel, are correctly dated as Triassic.

CAMPTONITE AND DIABASE DIKES

Dikes composed of slightly altered mafic minerals and which are younger than any of the other lithified formations, are locally common in Plymouth and Bridgewater. About thirty dikes were studied in place within the area and many loose blocks of others were noted in the glacial drift at numerous localities. The size of these bodies varies from a width of fifteen feet and length of over fifteen hundred feet in the larger ones, to a width of less than a foot and traceable length of only a few feet, in the smallest. The width of the average dike is about eighteen inches. Most of them trend approximately east and west across the strike of the country schists, but no exact system of orientation was observed. The general color is quite dark, either black, greenish black or dark grey, although one unique individual was found which was light in color in its central portion. Textural variations range from very fine aphanitic to coarse porphyritic, the latter with phenocrysts more than 3 cm. long. Jointing is very common in all the mafic dikes and they are readily reduced to small blocks by erosion. Weathering in turn reduces these to spheroidal lumps which constitute the usual residue along the line of surface outcrop of the rock. The dikes were found to be most common in the younger formations of the section, particularly the Missisquoi Group, and none was found in place in the pre-Cambrian rocks, although similar dikes have been found intrusive into the Mount Holly Series in nearby areas.

The dikes are divisible into two distinct types, according to their mineral composition, as determined by aid of the microscope. These are respectively *camptonites*, characterized by the presence of the hornblende, barkevekite, with feldspar close to calcic andesine; and *diabase*, characterized by augite with feldspar about labradorite in composition. It is often difficult to distinguish between these two rock types by a megascopic examination, but the camptonites are usually porphyritic with phenocrysts of barkevekite and occasionally feldspar, while the diabases are more commonly aphanitic. Structures resembling amygdules and containing a zeolite, or more rarely quartz, are abundant in many of the dikes. No opportunity was found for studying the field relation of the two rock types to each other, but because of their many characters in common they are believed by the writer to be essentially contemporaneous and probably comagmatic.

The age of these dikes can not be accurately determined in the Bridgewater-Plymouth area, but from the fact that they are apparently unaffected by dynamic metamorphism, it is probable

that they were unconsolidated until after the major movements of the Appalachian Revolution and in this respect are like the albite granite of the district. Camptonite and diabase in close association have been described from many localities in northern New England and southern Quebec,¹ often in undoubted genetic connection with intrusive stocks of alkaline rocks, such as those at Mount Ascutney and Cuttingsville in the vicinity of Bridgewater and Plymouth, Braintree in north central Vermont or Red Hill in New Hampshire. From the best evidence, particularly at Cuttingsville and Mount Ascutney, the camptonite represents the last phase of intrusion and is at least as young as post-Carboniferous. The diabase dikes have often been referred to the Triassic from their superficial resemblance to the dikes of that age in the Connecticut Valley, but no direct evidence can be offered in proof of this hypothesis and the closest limitation which can be placed on their age is post-Carboniferous and pre-Cretaceous.

An average camptonite dike is exposed beside the Bridgewater-Rutland highway two miles east of West Bridgewater and a few yards north of the Riverside School, in Bridgewater. This dike is about eighteen inches wide and is oriented N 70° E. The rock is porphyritic with phenocrysts of black hornblende, up to 1.0 cm. in length, in a dense, black, aphanitic matrix. The material weathers with difficulty to a light rusty brown, and is quite fresh a centimeter below the surface. In thin section the rock shows barkevekite, altered olivine, and abundant colorless pyroxene as large crystals in a ground mass of smaller crystals of plagioclase (calcic andesine), pyroxene and magnetite. The barkevekite is less abundant and the pyroxene (aegirite-augite) more abundant than in the most typical camptonites and this rock is considered to be closer in composition to the augite camptonite described by Kemp (1893, preceding citation) from the Lake Champlain district. The most striking difference between this and the typical camptonites is the lack of *small* barkevekite crystals in the ground mass.

¹ Hawes, G. W., "Type locality for Camptonite," Am. Jour. Sc. No. 3, Vol. XVII, 1879, p. 14.
 Kemp, J. F. and Marsters, V. F., Amer. Geol., Vol. IV, 1889, p. 97.
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 Daly, R. A., U. S. G. S. Bull. 209, 1903, pp. 86-87.
 Emerson, B. K., U. S. G. S. Bull. 597, 1917, pp. 205-206.
 Eggleston, J. W., Rpt. Vermont State Geologist, 1917-18, p. 189.
 Richardson, C. H., Rpt. Vermont State Geologist, 1923-24, p. 98.
 Bancroft, J. A. and Howard, W. V., Trans. Roy. Soc. Can. No. 3, Vol. XVII, 1923, p. 17.

On the steep west slope of Soltudus Mountain, in southern Plymouth, an acid camptonite dike ten feet wide outcrops with an east-west trend. This dike is light grey with black phenocrysts in the central portion, but grades into dense black aphanitic rock along the walls. The central portion is unique from that of other dikes in that it contains rounded, amygdale-like bodies of glassy quartz up to 1.0 cm. in diameter. The rock contains the following minerals: barkevekite, abundant as prisms and basal sections with inclusions of magnetite and apatite; pyroxene (aegirite-augite) as occasional subhedral phenocrysts; plagioclase, much altered and of indeterminate composition, forming the major portion of the ground mass of the rock; apatite, common as basal sections and as long prisms up to 1.5 mm. in length; magnetite, abundant as small anhedral grains; and sericite and calcite, present as alteration products of the feldspar. The marginal portion of the dike is much more aphanitic than the central portion, but contains the same essential minerals. The barkevekite is much more abundant and the plagioclase somewhat less altered. Occasional tiny areas of indeterminate isotropic material are present interstitial to the feldspar.

Three other dikes in Bridgewater, one in northeastern Bridgewater Hollow, a second on Southgate Mountain northeast of Bridgewater Corners, and a third in the Ottauquechee valley about two miles west of Bridgewater Corners, all showed the same composition and texture as the marginal portion of the dike described above. Each contained tiny patches of a cloudy, white, isotropic mineral of low index of refraction, probably analcite; and each was characterized by abundant small crystals of barkevekite, with some augite. A camptonitic dike rock from near the Bridgewater Hill road, one and a quarter miles east of West Bridgewater, was unusual in that it contained numerous small, white, amygdale-like bodies made up of a zeolite, which on analysis yielded: SiO_2 40.33, Al_2O_3 31.24, CaO 13.30, H_2O 12.59 and Na_2O 2.54 by difference.¹ This analysis is of necessity approximate because of the extremely small quantity of material available for examination, but nevertheless fixes the identity of the mineral as *thomsonite*.

Two very typical diabase dikes outcrop on the hillside north of Bridgewater Village. The first strikes with slight variations, N 12° E and can be followed for several hundred feet up the hillside between the elevations of 1,200 feet and 1,450 feet. The second outcrops at an elevation of 1,700 feet, due north of the village, and strikes N 40° E. Both dikes vary in width along the strike, but the first is about four feet wide and the latter six. Each is slightly porphyritic, bearing small crystals of black pyroxene even

¹ Analysis by Dr. A. H. Phillips, Princeton University, 1927.

in the marginal phases, but the ground mass is quite aphanitic and uniformly dark grey. The following minerals are present, as determined in thin sections: plagioclase, approximately calcic labradorite, abundant as small interlocking laths producing the typical diabasic texture; augite, in crystals of two generations, the first as large (2.0 mm.) phenocrysts with alteration rims, and the second as small grains interstitial to the feldspar; magnetite, abundant as small anhedral grains also interstitial to the plagioclase; and calcite common as small grains throughout the rock. The marginal phases of the dikes are essentially the same as the central portions except that the texture of the ground mass is much finer and two distinct generations of plagioclase are in evidence, the first as laths up to a millimeter in length and the second as a mesh of tiny needles surrounding the larger crystals. It is inferred from the above that some augite and plagioclase had crystallized from the intruded liquid before its introduction to its final resting place and the subsequent crystallization of the finer-grained ground mass.

Other diabase dikes from Bridgewater show the same essential characteristics as those described above.

STRUCTURAL GEOLOGY AND METAMORPHISM

STRUCTURAL GEOLOGY

The general structure of the sedimentary formations, younger than the pre-Cambrian, in Bridgewater and Plymouth, is a homocline with superimposed isoclinal folding on a small scale. All dips recorded in the area are to the east, with the exception of a few on the limbs of small isoclinal folds in the upper Missisquoi and the Ordovician rocks. The strike of all the formations is usually within a few degrees of north, but is very variable locally so that in a distance of a few yards along the strike it may vary ten degrees east to ten degrees west, or even more.

Practically no reliable data on structure can be obtained from the pre-Cambrian rocks because bedding planes have become obliterated during the process of metamorphism, and crumpling is often intense. Observations made by Whittle¹ on the Mendon Series have led him to postulate a series of sharp, compressed folds striking approximately north and overturned to the west so that the induced schistosity and stratification dip eastward. This theory is not contradicted by any observation made in the Plymouth area, but on the other hand is not definitely confirmed. The Bethel and Pinney Hollow Schists, because of their lithological uniformity throughout, give no clues to structure except along their margins. The other formations, however, contain

¹ Whittle, C. L., *Amer. Jour. Sc.*, Vol. XLVII, May, 1894, p. 354.

beds of sufficiently contrasting lithology to furnish unquestionable dips and strikes.

Conditions are such as to lead one to suspect isoclinal folding uniformly overturned from east to west throughout the entire section, but a close examination of the strata with this theory in mind showed no unquestioned repetition of beds except in one instance which is interpreted as a possible northward pitching anticline and syncline involving the base of the Pinney Hollow Schist and the underlying beds, just north of Plymouth Notch. Any isoclinal folding must then, with the exception noted above, be on a very small scale and in other words be intraformational rather than interformational. Most of the recognized folds range in size from less than a foot to about twenty-five feet in maximum width and have undoubtedly operated to thicken the section considerably. In several cases small, local overthrusts are developed in the non-competent Pinney Hollow Schist where small folds have been stretched to the breaking point. These faults all dip east at about forty-five degrees or at approximately the angle of the bedding. No major overthrusting was detected.

Igneous intrusions are much more common in the deformed eastern zone, particularly in the Missisquoi formation, and are practically absent from the western, older Cambrian section.

Joints are abundant in all the more massive formations of the section, particularly the Bethel and Pinney Hollow Schists and the "older Cambrian" rocks. Two distinct systems of joints are in evidence: the first approximately north and south parallel with the strike of the strata and dipping west at right angles to their dip, and the second oriented vertically and at right angles to the strike of the rocks.

METAMORPHISM

The intensity of metamorphism of the rocks in Bridgewater and Plymouth is in marked proportion to the complexity of structure. This is particularly true in the Cambrian rocks in which two distinct mineral facies zones are evident. The younger sedimentary formations, *viz.*, the Missisquoi and Bethel Schists, are characterized by an abundance of garnet (almandite?) and biotite with some amphibole, dependent upon the original bulk chemical composition of the rock. The metamorphosed igneous rocks of the same zone are characterized by uraltite (pargasite), epidote, and relic plagioclase and pyroxene in the dioritic type or by talc, ankerite and rarely tremolite in the very basic type. Sericite, albite, quartz, and magnetite are present in this zone as well as the next, so that they may be considered as persistent minerals.

In the western or older Cambrian zone the mineral assemblage is characterized by chlorite, sericite, albite, dolomite and

quartz. There is a marked absence of biotite and garnet in this zone, in spite of the fact that the original composition of some of the rocks in both zones was undoubtedly very similar, and hence similar groups of minerals might be expected after metamorphism. A comparison of the Pinney Hollow Schist of the lower zone with the Bethel Schist of the upper, affords an excellent example of the variant effects of metamorphism on rocks which were primarily similar. The Bethel Schist includes local areas in which the garnet content is at least ten per cent and scattered garnets are common in the entire formation, while in the Pinney Hollow Schist garnets and similar minerals are rare and poorly developed at best.

Coincident with the variation in minerals in the two zones, the rock structures are in contrast. In the upper zone isoclinal folding on a small scale is common. The rocks have quite evidently been subjected to much stress and have furthermore yielded freely, while in the lower zone folding is much less in evidence and the stress applied was absorbed by recrystallization and slight movements more or less in the plane of bedding, rather than by strong deformation.

The general setting described above suggests to the writer that there are here represented two mineral facies quite in agreement with those suggested by Eskola¹ in his paper on "The Mineral Facies of Rocks." The Pinney Hollow Schist and older rocks agree in detail with Eskola's "green schist facies" in their mineral composition. The Bethel and Missisquoi Schists on the other hand, have the characteristic mineral assemblage of his "amphibolite facies."

It is clear that equilibrium was not reached during the metamorphism of the eastern zone since some minerals inconsistent with the amphibolite facies, notably epidote, talc and ankerite, are present in the associated metamorphosed intrusives. These are, in this case, considered to be relic minerals of a metamorphic facies of lower grade. The fact that they are confined to the intrusive bodies of the zone suggests that slightly different factors were involved in the metamorphism of these bodies than in the surrounding country rock.

GEOLOGICAL HISTORY OF THE REGION

The geological history of the Plymouth-Bridgewater area, in itself, is indicative in a general way of the history of the entire eastern Green Mountain belt. It is necessary, however, to consider the geological record of nearby localities in order to include a more complete succession of events than is given only within the original area.

¹ Eskola, P., *Norsk Geol. Tidsskrift*, Vol. VI, 1920-21, pp. 143-194.

The pre-Cambrian history of the Green Mountains has never been established in detail, but many of the principal events have been recognized. Two distinct periods of sedimentation are shown in the two series of metamorphosed sediments, the Mount Holly and Mendon Series, described by Whittle. As mentioned above, both these series were referred to the Algonkian (as of 1889). According to present nomenclature the older series is most probably Archean, although the younger may still be regarded as Algonkian.

The oldest rocks in Plymouth, as indicated by the field relations, are the dolomites, quartzites, and chlorite schists of the Mount Holly Series. These may with reasonable certainty be considered as representing a time of marine sedimentation, although the complexity of structure in the region renders impossible the establishment of a definite stratigraphic section, and consequently nothing can be postulated concerning the details of the history of that particular time. Associated with the sedimentary rocks are bodies of amphibolite, particularly well exposed in Mount Holly township, adjoining Plymouth on the southwest. Some of these amphibolites may represent extrusives, but others are clearly intrusive into the schists and gneisses. Granite gneiss is particularly abundant and is, for the most part, clearly intrusive into the Mount Holly Series, as is shown on Salt Ash Mountain, in Plymouth, where much of the mountain is made up of coarse granite gneiss showing *lit par lit* injection into chloritic and hornblende schists.

A period of erosion intervened between the formation of the Mount Holly Series and the overlying Mendon group. Whittle mentions several occurrences of metamorphosed conglomerate at the base of the Mendon, although these were not found in the Plymouth area, the demarkation between the gneiss intruding the Mount Holly and the overlying Mendon is apparent. It is clear that a period of acute disturbance, uplift and erosion, followed or accompanied the intrusion of igneous rocks into the older pre-Cambrian and that later subsidence paved the way for the deposition of the Mendon Series, made up originally of sandstones, shales, and limestone. The difference in degree of complexity of structure between the two series indicates a probable disturbance of orogenic magnitude. Whittle emphasizes the importance of the amphibolites common in the town of Mount Holly, and interprets these as basalt *extrusives* which are present in the lower series but not in the Mendon Series, thus inferring a period of disturbance of the lower series which did not affect the upper one. In turn the structure of the Mendon Series, shown to be isoclinal overturned from east to west to produce a dip of about twenty-five degrees east, is much more complex than in the overlying (Cambrian) rocks. The period of disturbances following

the deposition and consolidation of the Mendon Series was evidently characterized by compression from the east jamming the strata against the resistant Archean rocks on the west, and doubtless forming schists and quartzites in the process.

The base of the section which is interpreted as Cambrian by the writer, is marked by the white, somewhat pebbly quartzite and dolomite, but not by a distinct conglomerate. It is evident from the shape of the best-preserved pebbles that active erosion, either fluvial or marine, was going on near by during the formation of these beds. The source of the sand and pebbles is probably to be found in the pre-Cambrian rocks to the west, especially since no probable source is known to be present to the eastward. There is thus an indication of the existence of a land mass in the position of the present central Green Mountain belt at the beginning of Cambrian sedimentation. This view is further substantiated by the presence of numerous large pebbles of gneiss and quartzite in somewhat higher members of the lower Cambrian group.

Considerable fluctuation of conditions is indicated by the variety of lithologic types in the older Cambrian rocks. This is interpreted as correlative to a near-shore environment in this case. It is probable that the dolomites, which are locally variable, represent deposition by chemical precipitation in lagoons or other isolated bodies of water along a shore zone, especially since the pebbles of blue vein-quartz, quartzite and orthoclase feldspar, found in close association, were clearly derived from a nearby land mass. Following the deposition of the sandstones, arkose and dolomite of the basal beds, came black shale followed again by fine sandstones and dolomite in northern Plymouth, and by conglomerate and dolomite in southern Plymouth. The conglomerate is interpreted as a fluvial deposit, probably a delta deposit, from its obviously local distribution along the strike. The large angular blocks of quartzite at the base of the formation offer further indication of a strictly local origin.

The formation overlying the conglomerate-sandstone-dolomite horizon was a laminated shaly sandstone, indicating by the change in size of clastic materials a probable change in conditions of sedimentation from near-shore to relatively off-shore deposition. There was fluctuation between the formation of small beds of pure sandstone and black shale, with all intermediate gradations.

Upon the older Cambrian group, the Pinney Hollow formation was deposited as a thick, relatively uniform series of shale beds. The environment and supply of material during this time was apparently constant and the material may have been derived from a more distant source than that of the older formations, since it was obviously better sorted and of finer grain, or else the

parent land mass was by this time reduced to a low flat plain and the sluggish streams flowing from it carried only fine materials. No carbon is noticeable in the Pinney Hollow formation as contrasted with the overlying Ottauquechee group, which was a black shale, and at present contains abundant disseminated carbon. A change in the composition of materials supplied is thus indicated, and the sandstones associated with the shale are a further proof of a change in environment. The black shale, as such, cannot be said to require any single set of conditions for its formation, but in this case, because of the associated sandstone, probably formed in relatively shallow water in an embayment between the present Green Mountain mass on the west, and some other land area on the east side of the present Connecticut River drainage area.

At the close of the time of deposition of the Ottauquechee black shale, conditions apparently reverted to those under which the Pinney Hollow formation was laid down, and the deposition of the Bethel formation took place. The oscillation between black shale and non-carbonaceous shale, at the base of the Bethel, indicates a general similarity of conditions of deposition of these two rocks, although in the former organic matter was abundant, and in the latter was practically absent. The uniformity of the Bethel formation indicates, again, stability of conditions of sedimentation over a considerable period of time, terminated by an abrupt change at the beginning of deposition of the Missisquoi Group. The latter was predominantly a thin-bedded sandstone with numerous shaly beds at first, with increasing proportion of quartz sand in the upper layers.

Some evidence of an unconformity between the Bethel and Missisquoi formations is indicated, but not proved, by the fact that several distinctive beds in the Missisquoi of northern Bridgewater seem to end against the Bethel Schist as they are traced southward. This would indicate a progressive overlap from north to south, but in view of the paucity of evidence, should be regarded as no more than a suggestion at present.

The evidence concerning the history of this region between the late Cambrian and early Ordovician times is of a very positive nature. The Irasburg conglomerate found at the base of the Ordovician in north central Vermont indicates a period of active erosion of the Cambrian rocks, prior to the deposition of the early Ordovician shales and limestones. There is no positive evidence in the Bridgewater area of folding of the Cambrian rocks prior to the Ordovician so that any movements were probably of the nature of simple uplifts. The amphibolites which are common as intrusives into the Missisquoi do not intrude the Ordovician rocks at any locality studied, but on the other hand no outcrop was noted in which the amphibolite could be interpreted as form-

ing part of the erosion surface on top of the Missisquoi. The exact age of the intrusion of the amphibolite is thus left in doubt, but it may be provisionally placed as late Cambrian until further evidence is found of their intrusion into younger formations. Similarly the steatite bodies representing intrusions into the various Cambrian rocks, may be dated as late Cambrian or younger. In view of the well-recognized association of periods of intrusion with mountain building, it is quite possible that the intrusion of the amphibolite bodies is to be connected with the post-Ordovician movements in this area, but judged from their degree of metamorphism they are older than the late Paleozoic movements and the unmetamorphosed granitic intrusives associated with the latter.

The Ordovician limestone and phyllite represent deposits of shale and sandy limestone formed in a marine trough or estuary extending along the east side of the Green Mountains from Quebec into Massachusetts. No younger Paleozoic formations, of undisputed age, have been found in Vermont, although a small area of Silurian is known in the Ammonoosuc¹ district of western New Hampshire and a small area of Devonian outcrops on the shore of Lake Memphremagog² in Quebec, near the Vermont line. The presence of these eroded remnants of marine Silurian and Devonian formations suggest that much of eastern Vermont was once covered by them. Unfortunately, the relationship between the structure of the Ordovician rocks and that of the younger strata has nowhere been observed and consequently no definite proof can be offered concerning the widely postulated orogenic movement at the close of the Ordovician. Clark³ in his paper on the Taconic Revolution summarizes this problem in its application to New England, and concludes that the evidence in favor of a *widespread* Taconic Revolution is negligible. It is thus questionable whether a disturbance at the close of the Ordovician can be postulated for the Green Mountain region.

Whether or not the Taconic Revolution in part contributed to the metamorphism of the rocks in the Plymouth and Bridgewater district, the Appalachian Revolution of the late Paleozoic was obviously a large factor. Lateral pressure from the east was effective in compressing the Ordovician and youngest Cambrian rocks into isoclinal folds. This effect dies away from east to west and the older strata of the section were not affected by strong folding, although they were recrystallized and rendered schistose. It is very probable that a range of mountains of considerable height occupied the present site of the Green Mountains and adjoining regions, in the late Paleozoic. Into the rocks of this

¹ Lahee, F. H., Amer. Jour. Sc. No. 4, Vol. XXXVI, pp. 231-251.

² Ellis, R. W., Ann. Rpt. Geol. Sur. Can., 1894, Part J, map.

³ Clark, T. H., Bost. Soc. Nat. Hist. Proc. No. 3, Vol. XXXVI, 1921, pp. 134-163.

range the present unmetamorphosed granites of the area were intruded. In view of the fact that the granite of Plymouth shows no gneissic structure, the writer believes that the date of intrusion and cooling must necessarily be placed during the last part of the Appalachian Revolution in this region. The basic dikes comprising the youngest lithified rocks of the area are probably either comagmatic with the granites and represent the last phases of intrusion of a common magma, or are to be correlated with the diabase intrusions of early Mesozoic age in the lower Connecticut valley.

During the Mesozoic, the Green Mountain region was probably undergoing active erosion and becoming worn down to the ultimate peneplain and low monadnocks of the Cretaceous. At the end of the Mesozoic the above peneplain was uplifted, and stream erosion during the Tertiary established the essential features of the present topography. At least one area of deposits of Tertiary age is known in Vermont, at Brandon, but no evidence of deposits of this age is found in Plymouth or Bridgewater. It has been suggested that the earthy iron ores found at Tyson are to be referred to this period, but no paleontological evidence was ever found there to the knowledge of the writer.

During the Pleistocene, the region was alternately covered and exposed by continental glaciers. Their chief effect was to modify the old Tertiary topography and to deposit glacial till and sorted sand and gravel in the valleys. Some modifications in drainage were effected during the Pleistocene, so that post-glacial streams have in many cases cut steep youthful gorges in new channels.

CORRELATION

The correlation of the section in the Bridgewater-Plymouth area with those of other nearby regions is rendered difficult by the total lack of recognizable fossils in any of the formations. It is thus impossible to assign an absolute age to any of the beds and correlation must be carried on through a comparison with the beds in other areas in view of their lithology and stratigraphic succession. The establishment of the continuity of formations by tracing them along the line of strike is obviously the best method of correlating separate sections of the type under consideration. Sufficient data for the application of this method are, however, not available for more than a limited correlation with other parts of central Vermont, eastern Quebec, or western Massachusetts. A comparison with formations in western Vermont, on the opposite side of the Green Mountains, is problematical at best.

The formations in Plymouth and Bridgewater have long been recognized as a part of a belt of related formations extending along the eastern side of the Green Mountains from Canada to

Massachusetts, although the individual members of the group have been subjected to but little study. The accompanying table (page 58) indicates the probable relation of the Plymouth-Bridgewater section to those to the north and south and includes a comparison of the names given to these formations by different writers. No attempt has been made in this table to express the relation between the formations of the area studied and those on the west side of the Green Mountains. Many authors, notably Pumpelly, Wolff, Dale, and Emerson in Massachusetts, E. Hitchcock, T. Sterry Hunt, and Whittle in Vermont and Ellis in Quebec, have attempted such a correlation and their conclusions will be considered below.

In the eastern Green Mountain belt the Ordovician limestone and phyllite constitute the most continuous and best-defined formation and below it the difficulty of correlation increases in proportion to the age of the formations compared, as a general rule. The pre-Cambrian rocks of the Green Mountain *axis* are, however, commonly considered to form a continuous, well-defined belt of outcrop from the southern border of Vermont nearly to the Chaudiere River in Quebec. The relation between these rocks and the pre-Cambrian of the Adirondacks, or of eastern New England, is unknown although C. H. Hitchcock¹ attempted such a correlation on a purely lithologic basis. This correlation on the present knowledge of New England geology can be regarded as little more than highly speculative. The Mendon Series was found by Whittle to overlie the central gneiss on either side of the Green Mountain axis and this constitutes the most certain proof of the anticlinal structure of the range, and the only evidence for the correlation of separate areas within the pre-Cambrian belt.

The only rock type of the older Cambrian for which it is possible to suggest a correlation is the dolomite of Plymouth. This dolomite agrees in stratigraphic position and association with those described by Dale² in Jamaica and Ludlow to the south and Rochester and Hancock to the north. Hitchcock and Hager have in addition mentioned dolomites in Andover, Sherburne and Granville in this same general belt, bordering the pre-Cambrian on the east. From the fact that the older Cambrian on the western side of the Green Mountains contains pink dolomite and quartzite in close association, it is very suggestive that the pink dolomite and white quartzite of Plymouth, in the same stratigraphic position, may form its counterpart on the east. This point was one of Hitchcock's major arguments for the anticlinal structure of the mountain range, but further evidence, particularly paleontological evidence, will be required to prove the point. The other older Cambrian formations are not sufficiently

¹ Hitchcock, C. H., Proc. A. A. A. Sc., Vol. III, September, 1884 (abst.).

² Dale, T. N., U. S. G. S. Bull. 589, 1915.

CORRELATION TABLE

1927	1861	1898-1917	1920	1908	1894	1914
E. L. Perry	E. Hitchcock and A. Hager	B. K. Emerson	C. H. Richardson	C. H. Richardson	R. W. Ells	T. N. Dale
Bridgewater and Plymouth, Vt.	Vermont	Western Mass.	Braintree, Vt.	Northern Vermont	Montreal Map Area, P. O.	Eastern Vermont
Waits River Limestone	Calcareous Mica Schist (in part)	Conway Schists	Waits River Limestone	Waits River Limestone (Washington Limestone)	Farnam Black Shales and Limestone	
Randolph Phyllite	Calcareous Mica Schist (in part)	Goshen Schists	Memphremagog Group (in part)	Memphremagog Group (in part)	Cambro-Silurian Slates of Mem- phremagog	
Missisquoi Group	Talcose Schist (in part) and Gneiss	Hawley Schist (?)	Missisquoi Group	Upper Cambrian Sericite Schist and Quartzite	"Cambrian Area east of Sutton Mountain"	
Bethel Schist	Talcose Schist (in part)	Savoy Schist (?)	Hydromica Schist	Pyritiferous Mica Schist (?)		
Ottawaquechee Group	Talcose Schist (in part) "Clay Slate"	(Chester Amphib- olite) (??)				
Pinney Hollow Schist	Talcose Schist (in part)	Rowe Schist				
Plymouth Dolo- mites	Dolomitic and Siliceous Lime- stones in the Talcose Schist					Marbles of Lud- low, Jamaica, Rochester, Han- cock and Gran- ville, Vt.
Albitic Schist	Talcose Schist (in part)	(Hoosac Schist?)				"Muscovite-biotite albite schist" of Jamaica, Vt. (?)

distinctive lithologically to serve as units for correlation; they are, however, included in the formation mapped by Hitchcock, in 1861, as the "talcose schist" and probably constitute the basal group of that series of rocks extending along the eastern side of the Green Mountains. There is at present no basis for judging the continuity of the lithology of these rocks as they are exposed in Plymouth.

The Pinney Hollow, Ottauquechee, and Bethel Schists are, like the older Cambrian rocks, included in Hitchcock's "talcose schist" and comprise the major part of that formation. The Ottauquechee was recognized as distinctive, however, and was called the "clay slate in the talcose schist." It is mapped as extending about twenty miles north of Bridgewater and also in a long line of outcrop in the northern part of the state. No equivalent for this phyllite can be found in the descriptions of rocks from the southern part of the state. The Pinney Hollow and Bethel Schists are believed to correspond respectively to the Rowe and Savoy Schists of the Massachusetts section¹ and hence to the upper Readsboro and Halifax schists in the adjoining section in southern Vermont, as described by Hubbard.² The lithology and stratigraphic sequence of the formations in the last-named areas is in good general agreement with those in the Bridgewater-Plymouth region and according to Hitchcock's map there is a continuity of formations in between. The Bethel Schist has been mapped, in its northward continuation from Bethel, as the "Hydromica Schist" in several reports by C. H. Richardson. It is probable that the "pyritiferous mica schist" of Troy, Vermont, described by the same author in 1908, is also to be correlated with the Bethel Schist since it has the same essential lithology and the correct stratigraphic position with regard to the more definite overlying formations. In comparing the sections on either side of the Green Mountains it is noticeable that corresponding with the great thicknesses of shale represented by the combined Pinney Hollow, Ottauquechee, and Bethel Schists on the east side, that there is a comparable thickness of Upper Cambrian slates and shales on the western side. Kieth,³ however, concludes from his studies in northwestern Vermont ". . . that there is only a small extension of the Ordovician and also of the Upper Cambrian eastward from the Green Mountains," so that the above comparison can be regarded as no more than a suggestion to be kept in mind during future work. The exact equivalent of the Pinney Hollow, Ottauquechee, and Bethel Schists in Quebec is unknown, but from maps at present available they may well correspond to a part of the Sillery formation.

¹ Emerson, B. K., U. S. G. S. Bull. 597, 1917, pp. 41-42 and map.

² Hubbard, G. H., Rpt. Vermont State Geologist, 1923-24, p. 291.

³ Kieth, A., Rpt. Vermont State Geologist, 1923-24, p. 132.

The Missisquoi Group offers less difficulty of correlation than do the underlying rocks, since they have been traced in a continuous belt of outcrop from the northern Vermont border to the area at present under consideration. They were up to 1918 referred to as the "Upper Cambrian sericite schist and quartzite" by Dr. Richardson, who has done most of the work of mapping this formation. The Missisquoi most probably corresponds to the upper part of the Sillery in Quebec. This idea was suggested as early as 1867 by C. H. Hitchcock¹ and is implied by Ells (1894) in his map of the Eastern Townships of Quebec, as found by comparing the latter with the map of some of the border towns in Vermont, published by Richardson in 1908, when the first work was done in separating the Missisquoi from the other associated formations. The position of the extension of the Missisquoi southward from Plymouth is uncertain, since none of the formations in the Massachusetts section is directly comparable in lithology. The Hawley Schist of the latter section bears, however, the same stratigraphic relation to the well-defined, overlying, Ordovician limestone as does the Missisquoi farther north, and is the most probable equivalent. The corresponding formation in southern Vermont has not been studied as yet.

The Waits River limestone and associated phyllite constitute the most widespread and best-known formation in eastern Vermont. The limestone and phyllite are the exact equivalent of Hitchcock's "Calcareous Mica-schist" of the older literature and have been traced as such from the Canadian border southward to the Massachusetts boundary, where they have been described by Emerson as the Conway and Goshen Schists. The writer has visited outcrops of the latter formations in northern Massachusetts and southern Vermont and found them to be lithologically identical with the Waits River and Randolph formations in north central Vermont. C. H. Hitchcock has used the name Conway Schist² in his study of the geology of the Hanover Quadrangle for the Waits River formation in the eastern part of its belt of outcrop. Richardson has traced the western border of the belt from the Canadian line southward as far as Reading, Vermont. The extension of the formation from the international boundary into Quebec has been mapped by Ellis³ and is called the "blackish or dark-grey limestone of Cambro-Silurian age" in his report on southeastern Quebec, and the "Farnam black shales and limestone" in his later report on the Montreal map area.⁴ The outcrop belt of the formation trends northeast from the border and extends at least across the Chaudiere River to the north.

¹ Hitchcock, C. H., *Proc. A. A. A. Sc.*, 1866-67, pp. 120-122.

² Hitchcock, C. H., *Rpt. Vermont State Geologist*, 1911-12, p. 101.

³ Ells, R. W., *Geol. Sur. Can. Ann. Rpt.*, 1886, Part J, map.

⁴ Also the above, 1894, Part J, map.

The Randolph Phyllite is considered by Richardson, as indicated in several of his reports, to belong to the Memphremagog group of slates and phyllites which occurs in and near the base of the Waits River Limestone in the northern section. This would imply an identity, in part at least, with the Magog shales of the Canadian section and which are known to be of middle Ordovician age from an extensive graptolite fauna found in them.

ECONOMIC GEOLOGY

DOLOMITE

Most of the dolomite beds of Plymouth and Bridgewater have at some time been used as a source of quick lime. Abandoned kilns are common in the vicinity of the dolomite outcrops and at least two kilns have been in recent use (1925). With few exceptions the lime-producing industry has never been systematically or continuously pursued in Plymouth, but has instead been a part-time occupation of men normally engaged in farming.

Much of the dolomite is too impure for making lime without some preliminary hand picking to remove quartz or micaceous layers, but in some parts of the beds the dolomite is quite pure and can be roasted directly as it comes from the quarry. The most troublesome impurity is quartz, present both as small veinlets and as small grains in the sandy phases of the formations. This quartz acts as a flux and causes sintering of the charge during the roasting process. Other impurities often present are iron and manganese producing the pink and red coloration in the lower dolomite, and carbonaceous matter coloring the dark phases of the upper beds. These do not seem to produce a markedly undesirable effect on the roasted product. The best dolomite for roasting is that in the upper bed a short distance north of Plymouth Notch, and in the lower bed north of Plymouth Union.

The kilns used in producing quick lime are all of the periodic type, six to ten feet in internal diameter, and about ten feet in height. All the kilns are built on hillsides so that they are readily charged from above and the "burned" lime drawn off from an opening at the base. Wood is used as a fuel. The lime produced is considered to be of excellent quality, but the cost of transporting the finished product to Ludlow does not permit of competition with other lime plants more favorably situated with respect to a railroad.

The dolomite from the small quarry near the head of Amherst Lake in southern Plymouth was used to a limited extent as a fancy marble for interior construction. The particular bed used for this purpose is metamorphosed intraformational conglomerate (or breccia) composed of rounded or subangular

phenoclasts of white dolomite in a matrix of carbonaceous, dark-grey dolomite. The bed is about a yard thick and is interstratified between beds of white dolomite. It is strongly jointed and consequently the proportion of waste in quarrying was too high for practical operation.

GOLD DEPOSITS

Gold is known to be widely distributed in Vermont, but it is rarely to be found in sufficient concentration to prove of commercial value. The town of Plymouth is exceptional in that it is the only town in the state in which gold deposits have yielded a profitable return on the time and energy expended in working them, but then only in a few instances. The deposits are of two types, quartz veins and placers, but only the latter have been worked at a profit.

Gold was first discovered in this district in 1851, in the town of Bridgewater, by Mathew Kennedy.¹ The exact location of the discovery vein is unknown, but was about one mile west of Bridgewater Center (Briggs) in Dailey Hollow and probably at about the top of the Bethel Schist (see map). The property later came to be known as the "Taggart vein" and was worked intermittently for a few years about 1859, but apparently much more money was expended on metallurgical machinery than was ever regained in the value of metal extracted. The gold was evidently very unevenly distributed in the vein and, although some pockets may have been as rich as is claimed, much of the ore was evidently low in metallic content as is shown by the following assay quoted by Dr. G. O. Smith²: gold, none; silver, 1.27 oz.; copper, 6.19 oz.; and lead, 6.26 oz. The vein was claimed to have yielded 18.7 oz. of gold per ton on ten tons treated. Other veins were prospected on the Ottauquechee River near Bridgewater Corners and also in Dailey Hollow one and a half miles due south of Chatauguay. The latter property was connected by road over the hill to an extensive mill at Chatauguay, but as far as could be learned by the writer, very little ore was treated and the whole project was a fraudulent scheme. In Plymouth, a mine was opened on a quartz vein intruding the Pinney Hollow Schist beside the Reading Pond Brook, about one and a half miles north-east of Tyson. This is now known locally as Foxes' Mine, from the name of its last operator, but was originally operated by the Rooks Mining Co. It seems never to have yielded a profit on the investment, and although native gold is unquestionably present in the mine, it is probably present in such small quantities in the aggregate as to make mining impractical. The mine is at present

¹ Hager, A. D., *et al.*, Rpt. Vermont State Geologist, Vol. II, 1861, p. 844.

² Smith, G. O., U. S. G. S. Bull. 225, 1903, p. 87.

in such a state of disrepair that the exploration of it is impossible, but from surface indications and exposures in two raises which reach the surface, the mine consists of drifts and raises along a very irregular quartz vein intruded in the plane of the schistosity of the country rock, which is here oriented N 3° W, dip 60° E. The mine is situated on a steep, southward sloping hillside, with an adit and ruins of a mill slightly above the level of the brook at the base of the hill and the upper workings, apparently a head house over a shaft, about 170 feet above the brook.

From the above it may be inferred that mining of the gold-quartz veins of the district is unprofitable, since the metallic contents are very low in total average and very irregular in distribution.

Gold in placer deposits has been known in Plymouth since about 1855, in which year prospecting is said to have yielded about \$500. In the next few years gold was found in the gravels of Reading Pond Brook and its tributary Buffalo Brook, Kingdom Brook, and the streams in the vicinity of Plymouth Five Corners. At the latter locality in the years 1858 and 1859, William Hankerson is reported to have washed several hundred dollars' worth of gold from the sediment in the bottom of a mill pond and during this same time about \$7,000 worth was estimated to have been washed in the entire town. These figures are unreliable at best, but perhaps give an idea as to the general magnitude of operations at that time. Since 1860 very little has been done in placer mining in Plymouth, although even at the present day some "panning" is carried on by local residents. The writer has observed the results of "panning" on Reading Pond Brook near Foxes' Mine and pieces of gold an eighth inch in diameter may be obtained from natural riffles formed by upright plates of schist in the bed of the stream. Considerable fine dust is also present with the small nuggets, but the labor involved in extracting the gold from between the plates of schist is worth more than the gold obtained. The process is hardly more than a holiday diversion at best.

The gold in the stream beds and the hillside gravels has been very probably derived from the denudation of gold-bearing quartz veins nearby. The concentration of the gold in this manner has, as seen above, produced a few deposits of commercial value, even though the original vein rocks do not constitute workable ore.

GRANITE

The granite previously described as outcropping on the south slope of Morrison Hill in Plymouth has been used to a limited extent as a stone for exterior construction, particularly in building a small church in Sherburne, near West Bridgewater. The

properties of this stone are essentially the same as those of the Bethel Granite which it so closely resembles. The church mentioned above was built in 1895 and at present, thirty years later, the rock shows no sign of decomposition or discoloration, although the mortar used in setting the blocks has in many places crumbled away.

Owing to the small size of the granite body and its general inaccessibility, it is improbable that this stone will ever have more than a very local use for fence posts and the foundations of buildings.

STEATITE

The deposits of steatite or, as it is locally called, "freestone," have been described above in considerable detail and little need be said of them at this time. From an economic standpoint the steatite deposits of Plymouth and Bridgewater are concluded to be of little value because of their small size, impurity, and distance from a railroad.

IRON

During the early part of the last century an iron furnace was operated in Plymouth, at Tyson, or as the locality was then called, Tyson's Furnace, from the name of the owner, Isaac Tyson. The ore used was said to be earthy hematite derived from the weathering of limestone such as that now present in the vicinity but some siderite was also used. The latter was obtained from several small lenticular deposits in various parts of the town, near Plymouth Union and Plymouth Kingdom in particular. Very little trace of the ore bodies is now visible and a ruined wall, across the road from the schoolhouse at Tyson, is all that marks the location of the furnace. The iron deposits have no present economic value.

ROAD METAL

Gravels used locally for road building are abundant in both Bridgewater and Plymouth. The best materials are found in the valleys and are composed of water sorted kame and river terrace gravels. These deposits are of Pleistocene age and were clearly formed by streams much larger than any now present in the region. The use of these gravels is necessarily quite local, but it is because of their abundance that good roads are made possible in the district.

